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US Army Corps
of Engineers

Water Resources
Support Center

Management of Bottom Sediments Containing Toxic Substances

Proceedings of the 6th U. S./Japan
Experts Meeting

16-18 February 1981
Tokyo, Japan

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The 6th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held 16-18 February 1981 in Tokyo, Japan. The meeting is held annually through an agreement with the U. S. Environmental Protection Agency and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

PREFACE

The 6th U. S./Japan Meeting on Management of Bottom Sediments Containing Toxic Substances was held in February in Tokyo, Japan. The meeting is held annually through an agreement with the U. S. Environmental Protection Agency (EPA) and the Japan Ministry of Transport to provide a forum for presentation of papers and in-depth discussions on dredging and disposal of contaminated sediment.

Topics of the presentations and discussions at the recent meeting have been more closely related to the Corps' dredging and regulatory missions than to EPA's mission. At the request of EPA, MG E. R. Heiberg, III, Director of Civil Works, agreed for the Corps to become the lead agency for the meetings. MG Heiberg appointed COL Maximilian Imhoff, Commander and Director of the Water Resources Support Center (WRSC), as the U. S. Chairman.

Assistance in coordination of the organizational activities and publication of this report was provided by Mr. Thomas R. Patin, program assistant, and Mr. Charles C. Calhoun, Jr., Program Manager, Dredging Operations Technical Support Program (DOTS), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

CONTENTS

ATTENDEES

6th ANNUAL MEETING
U. S./JAPAN EXPERTS MEETING

U. S. Delegation

COL Maximilian Imhoff, Cochairman	CE, Commander and Director Water Resources Support Center
Mr. Charles C. Calhoun	CE, Waterways Experiment Station
Dr. Robert M. Engler	CE, Waterways Experiment Station
COL Douglas Haller	CE, District Engineer, Norfolk District
Dr. John Herbich	Ocean Engineering Program, Texas A&M University
Mr. Jim Mansky	CE, New York District
Mr. John Martin	President, Dredge Technology Corp.
Mr. William Murden	CE, Chief, Dredging Division, Water Resources Support Center
Mr. Thomas R. Patin	CE, Waterways Experiment Station
Dr. Spencer Peterson	EPA, Corvallis Environmental Research Laboratory

Japanese Delegation

Rikuro Takata Cochairman	Bureau of Ports and Harbours Ministry of Transport (MOT)
Yoshihisa Fujita	Environmental Protection Section 3rd District Port Construction Bureau, MOT
Shoichi Hamaguchi	Tsu Civil Engineering Office, Mie Prefecture
Takeshi Horie	Purification Hydraulics Laboratory Marine Hydrodynamics Division Port and Harbour Research Institute, MOT
Hiromi Koba	Japan Dredging and Reclamation Engineering Association
Hidehiko Kuroda	Environmental Protection Section 3rd District Port Construction Bureau, MOT

Yasuyuki Nakayama	Bureau of Ports and Harbours, MOT
Mitsumasa Okada	National Institute for Environmental Studies
Toshiki Oshio	Water Quality Control Division, Water Quality Bureau, Environmental Agency
Naojiro Oshita	Osaka Municipal Technical Research Institute
S. Sadamichi	Izumo Work Office, Chugoku Regional Construction Bureau, Ministry of Construction
Masanori Sakurai	Section of Port and Harbours, Civil Engineering Division of Aomori Prefecture
Ryuichi Sudo	Laboratory of Fresh Water Environment, National Institute for Environmental Studies, Environmental Agency
Isao Tabuse	River-Administration Section Wakayama Prefecture
Yasufumi Umehara	Soil Dynamics Laboratory, Soils Division Port and Harbour Research Institute, MOT, Overseas Coastal Area Development Institute of Japan
Tatsuo Yoshida	Japan Bottom Sediment Management Association
Kouki Zen	Soil Dynamics Laboratory, Soils Division Port and Harbour Research Institute, MOT, Overseas Coastal Area Development Institute of Japan

AGENDA

6th U. S./JAPAN EXPERTS MEETING ON MANAGEMENT
OF BOTTOM SEDIMENTS CONTAINING
TOXIC SUBSTANCES

Ministry of Transport
Tokyo, Japan

16-18 February 1981

Cochairmen

COL Maximilian Imhoff

U. S. Army Corps of Engineers, Water Resources Support Center

Mr. Rikuro Takata

Director, Environmental Protection Division
Bureau of Ports and Harbours, Ministry of Transport

Monday, February 16, 1981

10:00-10:30	Opening Addresses, Cochairmen
10:30-11:00	Outline of Sea Bottom Management in Ports and Harbours and Sea Water Areas in Japan - R. Takata, Environmental Protection Division, Ports and Harbours Bureau, Ministry of Transport
11:00-11:30	Current Issue in Water Pollution Control Administration in Japan - T. Oshio, Water Quality Control Division, Water Quality Bureau, Environment Agency
11:30-12:00	Demonstration of Advanced Techniques to Dredge Contaminated Materials (Kepone in the James River) - D. Haller, Corps of Engineers, Norfolk District
12:00-13:30	Lunch
13:30-14:00	Some Comments on Dredging Work in Japan - H. Koba, Japan Dredging and Reclamation Engineering Association
14:00-14:30	Result of Monitoring Aquatic and Habitat Development Field Sites and Verifying Operational Procedures - C. Calhoun, Corps of Engineers, Waterways Experiment Station

14:30-15:00	Water Quality Improvement by Retardation of Nutrient Release-Estimation and Analysis by a Simplified Model - T. Horie and K. Hosokawa, Purification Hydraulics Laboratory, Marine Hydrodynamics Division, Port and Harbour Research Institute, MOT
15:00-15:30	Coffee Break
15:30-16:00	Dissolved Oxygen Consumption in Lake Sediments - R. Sudo and M. Okada, Laboratory of Fresh Water Environment, National Institute for Environmental Studies, Environment Agency
16:00-16:30	Dredging and Nutrient Inactivation as Lake Restoration Techniques: A Comparison - S. Peterson, Environmental Protection Agency, Corvallis Laboratory
16:30-17:00	Effects of External and Internal Loading of Pollutants Upon Water Quality - T. Yoshida, Japan Bottom Sediments Management Association
17:00-17:30	Consolidation and Settling Characteristics of Very Soft Contaminated Sediments - Y. Umehara, Soil Dynamics Laboratory, Soils Division Port and Harbour Research Institute, MOT, and K. Zen, Overseas Coastal Area Development Institute of Japan
18:00-20:00	Reception at Matsumotoro

Tuesday, February 17, 1981

10:00-10:30	Pollution of Sea Water in Hachinohe Harbour and its Restoration by Sediment Removal - M. Sakurai, Section of Port and Harbours, Civil Engineering Division of Aomori Prefecture
10:30-11:00	Environmental Significance of New York Harbour Dredging in Relation to Disposal - J. Mansky, Corps of Engineers, New York District
11:00-11:30	How to Dredge up and Treat Bottom Sediment in the River Waka - I. Tabuse, River-Administration Section, Wakayama Prefecture
	On the New Method of Treating Bottom Sediment by a Silicic Coagulant (SIL-B Treatment Method) - N. Oshita, Osaka Municipal Technical Research Institute
11:30-12:00	Pollution Studies at Tsu-Matsuzaka Harbour and Removal of Sediment at Estuaries Near it - S. Hamaguchi, Tsu Civil Engineering Office, Mie Prefecture

12:00-13:30	Lunch
13:30-14:00	Innovative Dredging Techniques - J. Martin, Dredging Technology Corp.
14:00-14:30	Activities of Center for Dredging Studies-Texas A&M University - J. Herbich, Texas A&M University
14:30-15:00	Studies on Lake Pollution of Nakanoumi and on its Restoration - S. Sadamichi, Izumo Work Office, Chugoku Regional Construction Bureau, Ministry of Construction
15:00-15:30	Coffee Break
15:30-16:00	Bottom Sediment Improvement Effect on Water Quality--Effect of Dredging and Clean Sand Layover - H. Kuroda and Y. Fujita, Environmental Protection Section, 3rd District Port Construction Bureau, MOT
16:00-16:30	Interpretation of Bioaccumulation for Ocean Dumping Purposes - R. Engler, Corps of Engineers, Waterways Experiment Station
16:30-17:00	Productive Use of Dredged Material - T. Patin, Corps of Engineers, Waterways Experiment Station

Wednesday, February 18, 1981

10:00-10:30	Final Discussion, All Participants
10:30-11:00	Closing Addresses
11:00	Bus to Port and Harbour Research Institute
14:00	Arrive Port and Harbour Research Institute
16:30	Bus to Tokyo
19:00	Arrive Tokyo

JOINT COMMUNIQUE

The 6th U. S./Japan Experts Meeting on Management of Bottom Sediments Containing Toxic Substances was held by the United States (COL Maximilian Imhoff, Commander/Director, Water Resources Support Center, U. S. Army Corps of Engineers) and Japanese (Rikuro Takata, Director, Environmental Protection Division, Bureau of Ports and Harbours, Ministry of Transport) Co-chairmen Feb. 16-18, 1981 at Tokyo, Japan. The Purpose of the conference is to exchange information in both regulatory and technical areas relevant to bottom sediments management and to explore areas where joint effort would be fruitful.

United States and Japanese experts presented papers on several technical and managerial subjects including: outline of sea bottom management and water pollution control administration in Japan, advanced techniques to dredge contaminated materials in the James River, results of monitoring aquatic and habitat development, two analytical methods for estimating the effect of released nutrient and external loading, dissolved oxygen consumption in lake sediments, dredging and nutrient inactivation as lake restoration techniques, consolidation and settling characteristics of super-soft contaminated sediments, environmental significance of New York Harbour dredging in relation to disposal, new method of treating bottom sediment by silicic coagulant, innovative dredging technique, activity of Center for Dredging Studies Texas A&M University, lake pollution of Nakanoumi and on its restoration, bottom sediment improvement effect on water quality, interpretation of bioaccumulation for ocean dumping purposes, productive use of dredged material, pollution studies and removal of sediment at Tsu-Matsuzaka and Hachinohe Harbour.

There was general agreement that this conference has been highly fruitful in meeting its major goal: to exchange the most recent information in techniques management and the environmental effects of sediment material containing toxics and other pollutants. It is agreed that the next meeting should be held in the United States and the dates will be decided jointly by both countries.

Director, Environmental
Protection Division, Bureau
of Ports and Harbours,
Ministry of Transport

Rikuro Takata
Mar. 24, 1981

Commander/Director, Water Resources
Support Center, U. S. Army Corps
of Engineers

COL Maximilian Imhoff
Mar. 24, 1981

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per hour	0.3048	metres per hour
horsepower (550 foot-pounds per second)	745.6999	watts
inches	25.4	millimetres
knots (international)	0.5144444	metres per second
miles (U. S. statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square nautical miles	3.43	square kilometres
tons (2,000 lb, mass)	907.1847	kilograms

OUTLINE OF SEA BOTTOM MANAGEMENT IN PORTS, HARBOURS, AND SEAWATER AREAS IN JAPAN

Rikuo Takata, Director

Environmental Protection Division
Bureau of Ports and Harbours
Ministry of Transport

1. Preface.

The polluted bottom sediments purification works currently being conducted in ports, harbours, and seawater areas as part of Port Improvement Works are:

1) Port Pollution Control Works conducted to remove the polluted bottom sediments containing toxic or organic substances from the seabed in ports and harbours.

2) Purification works to remove organic pollutants deposited on the seabed in inner ports and inland waters conducted as part of the Marine Environment Improvement Pilot Project.

The first has been conducted since 1972 as a subsidized project (subsidy ratio: 50%) and the second has been conducted since 1979 as a government executed project.

2. Port Pollution Control Works.

Table 1 shows the framework of the Port Pollution Control Works. As of 1980, dredging of a total of about 22 million m^3 and earthing of about 100,000 m^3 have been either planned or conducted at 33 ports throughout the country to purify the bottom sediments containing toxic substances such as mercury and PCB or organisms in

large quantities in the bottom sediments at an estimated total cost of ¥110,000 million.

Of these ports, the business establishments causing the seabed pollution are known for 10 ports and they are, accordingly, to bear part of the costs in proportion to the degree of their responsibility (Table 2).

The development of the works is as shown in Table 3; they are to be conducted at 22 ports by the end of fiscal 1980 at a cost of ¥55,300 million. During fiscal 1980, as Table 4 shows, 13 ports are to be covered at a total cost of ¥6,150 million. The works to be carried out at various ports are outlined below.

PORT OF TOKYO

1) Water pollution is extensive in the inner part of the port and canals. The polluted organic sediments are due to industrial effluent and urban drainage, causing offensive odors and having adverse effects on the environment.
2) Under the Environmental Pollution Control Program (Secondary Areas 1972-81), approved on December 19, 1972, it was decided to dredge a total of about 2,593,000m^3 of polluted sediments deposited in the canals and elsewhere in the three areas of Koto, Shibaura, and Konan as part of the Port Pollution Control Work to ensure environmental protection.
3) This work commenced in fiscal 1972 with a total of about 1,442,000m^3 of polluted bottom sediments being dredged by fiscal 1979.
4) During fiscal 1980, the work is to be continued by dredging a

total of about 227,000m^3 polluted bottom sediments in the Koto and Shibaura areas (dredging costs for fiscal 1980: ¥1,440 million, subsidy: ¥720 million, rate of growth: 1.240).

5) The rate of progress against the entire program: 48.9% at the end of fiscal 1980.

PORT OF YOKOHAMA

1) Water pollution is extensive in the canals and rivers in the port area. The polluted organic sediments are due to industrial effluent and household sewage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program (Secondary Areas 1972-81), approved on December 19, 1972, it was decided to dredge a total of about 1,415,000m^3 of polluted sediments deposited in the three areas of Ooka and Boshi river systems and the Ebisu Daikoku Canal, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1973 with a total of about 947,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 68,000m^3 of polluted sediments is to be dredged in the Ebisu Daikoku Canal and the Boshi river system (dreding costs for fiscal 1980: ¥150 million, subsidy: ¥75 million, rate of growth:0.562).

5) The rate of progress against the entire program: 67.2% at the end of fiscal 1980.

PORT OF NAGOYA

1) Water pollution is extensive in the canals and rivers in the port area. The polluted organic sediments are due to industrial effluent and urban drainage, causing offensive odors and having adverse effects on the environment with highly concentrated mercury in the sediments in some parts of the area.

2) Under the Environmental Pollution Control Program (Tertiary Areas 1972-81), approved on December 19, 1972, it was decided to dredge a total of about 691,000m^3 of polluted sediments deposited in three areas, the port and the Nakagawa and Oe Canals, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1972 with a total of about 507,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 11,000m^3 of polluted sediments containing mercury deposited in the port (Lots 7-8 Canal) and the Oe Canal is to be dredged (dredging costs for fiscal 1980: ¥295 million, subsidy: ¥53.1 million, rate of growth:9.158).

5) The rate of progress against the entire program: 21.0% at the end of fiscal 1980.

PORT OF YOKKAICHI

1) The environment in the Shiobama area of the port is adversely affected by pollution. The polluted sediments contain oil and mercury due to industrial effluent from oil refining

and chemical industries, resulting in the appearance of fish with an offensive odor in the coastal fishing ground, pollution of the bottom with mercury, and offensive odors generating from the bottom sediments.

2) Under the Environmental Pollution Control Program (Primary Areas 1971-82), approved on December 1, 1970, it was decided to dredge a total of about 1,800,000m^3 of polluted sediments deposited in the Shiobama area, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1974 with a total of about 1,151,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 49,000m^3 of polluted sediments is to be dredged in the Shiobama area to complete the program (dredging costs for fiscal 1980: ¥603 million, subsidy: ¥50.4 million, rate of growth:0.551).

5) Rate of progress against the entire program: 100% at the end of fiscal 1980.

PORT OF OSAKA

1) Water pollution is extensive in the rivers in the port area. The polluted organic sediments are due to industrial effluent and urban drainage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program

(Secondary Areas 1972-81), approved on December 19, 1972, it was decided to dredge a total of about 2,398,000m^3 of polluted sediments deposited in the port (port sections of the Aji, Shirinashi, and Kizu rivers), as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1973 with a total of about 1,252,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 164,000m^3 of polluted sediments is to be dredged in the port area (dredging costs for fiscal 1980: ¥702 million, subsidy: ¥351 million, rate of growth:1.371).

5) The rate of progress against the entire program: 53.4%.

PORT OF HIMEJI

1) Water pollution is extensive in the rivers in the port area The organic sludge is due to the drainage from a leather plant and urban drainage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program (Quarternary Areas 1973-82), approved on December 18, 1973, it was decided to dredge a total of about 533,000m^3 of polluted sediments deposited in the three areas of Aboshi, Harima, and Yaka to ensure environmental protection.

3) This work commenced in fiscal 1974 with a total of about 103,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 344,000m^3 of polluted

sediments is to be dredged in the Yaka, Harima, and Aboshi areas (dredging costs: ¥300 million, subsidy: ¥150 million, rate of growth:1.111).

5) The rate of progress against the entire program: 25.3%.

PORT OF HACHINOE

1) Water pollution is extensive in the First Industrial Port. The polluted organic sediments are due to industrial effluent and urban drainage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program (Sexenary Areas 1975-79), approved on February 17, 1976, it was decided to dredge a total of about 235,000m^3 of polluted sediments deposited in the First Industrial Port area, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1979 with a total of about 94,000m^3 of polluted bottom sediments being dredged.

4) During fiscal 1980, a total of about 141,000m^3 of the remaining polluted sediments is to be dredged to complete the work.

5) The rate of progress at the end of fiscal 1980 against the entire program: 100%.

PORT OF TSU MATSUZAKA

1) Water pollution is extensive in the rivers in the port area. The polluted organic sediments are due to urban drainage, causing offensive odors and having adverse effects on the environment.

2) With the designation by the Minister of Home Affairs, it was decided to dredge a total of about 452,000m^3 of polluted sediments deposited in the port, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1979 with a total of about 10,000m^3 being dredged.

4) During fiscal 1980, a total of about 146,000m^3 of polluted sediments is to be dredged (dredging costs for fiscal 1980: ¥582 million, subsidy: ¥291 million, rate of growth:15.347).

5) The rate of progress at the end of fiscal 1980 against the entire program: 34.4%.

PORT OF TAGONOURA

1) Water pollution is extensive in the port. The deposition of PCB and the polluted organic sediments are due to the drainage from numerous paper mills located behind the port, causing offensive odors and having adverse effects on the environment.

2) With the designation by the Minister of Home Affairs (1971-72), and under the Environmental Pollution Control Program (Quarternary Areas 1973-82), approved on December 18, 1973, it was decided to dredge a total of about 1,714,000m^3 of polluted sediments, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1971 (with subsidy from fiscal 1972) with a total of 1,638,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 75,000m^3 of polluted sediments in the Suzukawa area is to be dredged to complete the work (dredging costs for fiscal 1980: ¥188 million, subsidy: ¥45.8 million, rate of growth:0.163).

5) The rate of progress at the end of fiscal 1980 against the entire program: 100%.

PORT OF AMAGASAKI NISHINOMIYA ASHIYA

1) Water pollution is extensive in the canals and rivers in the port area. The polluted organic sediments are due to industrial effluent and urban drainage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program (Tertiary Areas 1972-81), approved on December 19, 1972, it was decided to dredge a total of about 291,000m^3 of polluted bottom sediments in Amagasaki and Nishinomiya areas, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1977 with a total of about 171,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 56,000m^3 of polluted sediments is to be dredged, continuing with Amagasaki area and commencing with Nishinomiya (dredging costs for fiscal 1980: ¥200 million, subsidy: ¥100 million, rate of growth: 0.667).

5) The rate of progress at the end of fiscal 1980 against the entire program: 75.9%.

PORT OF HIGASHI HARIMA

1) Water pollution is extensive in the rivers in the port area. The polluted organic sediments are due to urban drainage, causing offensive odors and having adverse effects on the environment.

2) Under the Environmental Pollution Control Program (Quarternary Areas 1973-82), approved on December 18, 1973, it was decided to dredge a total of about 50,000m^3 of polluted sediments deposited in the Beppu area, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1978 with a total of about 7,000m^3 of polluted bottom sediments being dredged by fiscal 1979.

4) During fiscal 1980, a total of about 3,000m^3 of polluted sediments is to be dredged (dredging costs for fiscal 1980: ¥30 million, subsidy: ¥15 million, rate of growth:1.000).

5) The rate of progress at the end of fiscal 1980 against the entire program: 19.5%.

PORT OF MINAMATA

1) Water pollution is of a serious nature in the port. The polluted sediments contain mercury due to the drainage from the Minamata Plant of the Chisso Company Ltd. This drainage contaminates fish and shellfish and causes the Minamata Disease, thus having a serious impact on the environment.

2) With the designation by the Minister of Home Affairs, it was decided to dredge a total of about 1,663,000m^3 of polluted

sediments deposited in the port, containing mercury of over 25ppm, as part of the Port Pollution Control Work to ensure environmental protection.

3) This work commenced in fiscal 1975 (with the 1974 budget) with a total of about 775,000m^3 of polluted bottom sediments being dredged by fiscal 1979 (including the construction of temporary cofferdams).

4) During 1980, a total of about 69,000m^3 of polluted sediments in the port is to be dredged, including the construction of alternative facilities (dredging costs for fiscal 1980: ¥930 million, subsidy: ¥178.5 million, rate of growth: 0.977 for dredging costs and 1.256 for subsidy).

5) The rate of progress at the end of fiscal 1980 against the entire program: 40.2%.

PORT OF OMUTA

1) Water pollution is extensive. The polluted sediments contain mercury due to the drainage from various plants located along the Omuta River, causing offensive odors and having adverse effects on the environment and also on habitat for fish and shellfish.

2) Under the Environmental Pollution Control Program (Quarternary Areas 1973-82), approved on December 18, 1973, it was decided to dredge a total of about 608,000m^3 polluted sediments containing mercury of over 25ppm, as part of the Port Pollution Control Work (river section of 363,000m^3 to be dredged; mooring basin of 745,000m^3 to be earthed) to ensure environmental protection.

3) This work commenced in fiscal 1973 with a total of about 363,000m^3 polluted bottom sediments in the port section of the Omuta River being dredged and a total of about 167,000m^3 in the basin section being treated (68,000m^2 earthed).

4) During fiscal 1980, a total of about 11,000m^2 is to be earthed (completion of alternative facilities to cover the sludge in the basin section and the promotion of earthing). (Costs for fiscal 1980: ¥300 million, subsidy: ¥31.1 million, rate of growth:0.536.)

5) The rate of progress at the end of fiscal 1980 against the entire program: 90.7%.

3. Marine Environment Improvement Pilot Project.

A marine environment improvement pilot project is intended to carry out seabed purification in a part of the waters where seabed pollution is extensive to ascertain the method and effect of purification in enclosed inner bays and inland sea.

This project is at the stage of implementation design survey with extensive pollution field survey, environment improvement forecast survey, test construction, effect follow-up survey, construction method survey, etc., being carried out in those waters shown in Fig. 1. For fiscal 1980, project costs are allocated as follows: 15 million yen for Osaka Bay, 200 million yen for Hiroshima Bay, 50 million yen for Suoonada, and 100 million yen for Ise Bay (see Table 5).

Table 1: System of Port Pollution Control Works

Outline of works	Laws and ordinances concerning subsidy	Ratio of subsidy	Remarks
Work to prevent pollution at ports and harbours under the Law concerning Special Government Financial Measures for Pollution Control Project or the Port and Habour Law. (Work under the Port and Habour Law)	Paragraphs 1 and 3, Article 3, Law concerning Special Government Financial Measures for Pollution Control Project	1/2	Pollution control program: under Paragraph 2, Article 19, Basic Law for Environmental Pollution Control. Note: As for those projects which come under the Law concerning Entrepreneurs' Bearing of the Cost of Public Pollution Control Works, the amount obtained by multiplying that obtained by deducting the entrepreneur's share from the cost by the ratio given on the left is to be subsidized.
Facilities to improve port pollution control (raceways to purify polluted water, buffer zones to control pollution, other facilities to control pollution at ports and harbours). (Work under the Law concerning Special Government Financial Measures for Pollution Control Project)	Item 4, Paragraph 1, Article 43, Port and Habour Law	5/10	
Dredging and raceway projects carried out under pollution control programs or designation by the Minister of Home Affairs, and other projects prescribed by ordinances (earthing, ploughing, and the installation of oil and dust fencing).	Paragraph 1, Article 2, Law for Port Construction for Development of Hokkaido.	5/10	
	Paragraph 1, Article 2, Law for Special Measures for Development of Okinawa Enforcement Ordinance	6/10	

Table 2: Overall plan for polluted sediments treatement under the Port Pollution Control Works

Port.	Area.	Pollutant.	Standards for removal.	Quantity (thousand m³)	Cost (million yen).	Environmental Pollution Control Program	Enterpreneur's bearing of the cost.
Tokyo			Total points based on the following:	2,626	10,849	Tokyo Area Environmental Pollution Control program.	
	Koto	Organic matter	Ignition loss (%) / Evaluation points	1,176	5,492		No
	Shibaura.	"	<5 : 0 5≦ <15 : 3 15≦ : 6	1,190	4,576		"
	Konan.	"		261	781		"
Yokohama			COD (mg/g) <13 : 0 13≦ <20 : 1 20≦ <30 : 2 30≦ <40 : 4 40≦ : 6	1,624	2,463	Kanagawa Area Environmental Pollution Control Program.	
	Ooka River	Organic matter.	Sulfide (mg/g) <0.6 : 0 0.6≦ <1.0 : 1 1.0≦ <5.0 : 2 5.0≦ <10.0 : 4 10.0≦ : 6	275	401		No.
	Katabita River	"		646	1,074		"
	Ebisu Daikoku.	"		702	988		"
Shimizu.	Port area.	Organic matter.	Undecided.	420	3,400	Shizuoka-Shimizu Environmental Pollution Control Program.	No.
Nagoya		Organic matter	When two or more of the following apply:	691	5,427	Nagoya Area Environmental Pollution Control Program	
	Horikawa River mouth		Ignition loss 10%	194	293		No
	Nakagawa River mouth.		COD 20mg/g	26	27		"
	Arako River mouth		Sulfide 1mg/g	64	106		"
	Nakagawa Canal			220	465		"
	Nos. 7-8 Lot Canal.	Mercury.	Mercury 24ppm	58	1,625		Yes.
	Ooe River.	Mercury/PCB	Mercury 25ppm PCB 10ppm	127	2,911		"
Yokkaichi	Shiobama	Mercury Oil	Mercury 6ppm Oil 4,000ppm	1,800	6,553	Yokkaichi Area Environmental Pollution Control Program.	Yes
Wakayama Shimotsu.	Inner port	Organic matter	Ignition loss 15%.	100	250	Wakayama Area Environmental Pollution Control Program	No
Osaka	Port area	Organic matter.	Ignition loss 15%.	2,562	9,722	Osaka Area Environmental Pollution Control Program	"
Himeji	Yaka.	Organic matter.	I.L. 10%, COD 20mg/g, S 0.9mg/g	768	6,190	Harima-South Area Environmental Pollution Control Program.	No
	Harima	"	I.L. 15%, COD 30mg/g, S 1.0mg/g	162	1,310		"
	Aboshi	"	" " "	172	1,850		"
			When two or more of the above apply:	434	3,030		
Kita-Kyushu.	Dokai.	Organic matter. Matters of health hazard	Undecided	3,300	12,800	Kita-Kyushu Environmental Pollution Control Program.	Yes

Sakata.	Ohama.	Mercury.	Mercury 20ppm.	71	670	Designated by the Minister of Home Affairs.	Yes
Hachinohe.	First Industrial port.	Organic matter.	When two or more of the following apply: COD 30 mg/g, sulfide 1 mg/g I.L. 10%.	235	720	Hachinoe Area Environmental Pollution Control Program.	No
Shiogama.	Nakanoshima.	Organic matter.	Ignition loss 15%.	47	430	Designated by the Minister of Home Affairs; Sendai Bay Area Environmental Pollution Control Program.	Yes
Tagonoura.	Suzu River.	Organic. PCB.	PCB 10ppm.	1,714	5,958	Designated by the Minister of Home Affairs; Fuji Area Environmental Pollution Control Program.	Yes
Mikawa	Yagyu Canal	organic matter	COD 10mg/g, ignition loss 10% and sulfide 1mg/g.	51	183	Designated by the Minister of Home Affairs	No
Kinuura	Hokinan	organic matter		27	82	Kinuura Nishi-Mikawa Area Environmental Pollution Control Program.	No
Tsu-Matsuzaka	Akogigaura	organic matter	sulfide 1 mg/g	472	2,490	Designated by the Ministry of Home Affairs	No
Owase	port Area	organic matter	undecided	69	178	〃	〃
Amagasaki Nishinomiya Ashiya	Amagasaki Nishinomiya	〃 〃	When two or more of the following apply I.L. 15% COD 30 mg/g Sulfide 1.2 mg/g	737 697 40	2,490 2,300 190	Hyogo-East Area Environmental Pollution Control Program	〃
Higashi harima	Beppu	〃	〃	37	232	Harima-South Area Environmental Pollution Control Program	〃
Mizushima	Mizushima	oil	oil 1500ppm	813	6,455	Mizushima Area 〃	Yes
Kure	Hiro	organic matter	I.L. 24%, COD 50mg/g Sulfide 1mg/g, one of them	240	2,973	Hiroshima-Kure Area 〃	〃
Takamatsu	Senba river	〃 PCB	PCB 10ppm	34	640	Kagawa Area 〃	〃
Toyo	Mibu	organic matter	Odor Intensity index 2.5	20	60	Toyo Area 〃	No
Matsuyama	Innerport Wake	〃 〃	undecided 〃	147 122 25	489 404 85	designated by the Ministry of Home Affairs	〃
Iwakuni	Muronoki	〃	I.L. 15%	300	500	Iwakuni Area Environmental pollution control Program	Yes

Mitajiri Nakazeki	Tsukiji	organic matter	I.L. 15%	251	390	Shunan Area Environmental Protection Control Program	Yes
Ube	Honko	"	"	492	800	Shimonoseki Ube Area " "	Yes
Minamata	Hyakken	Mercury	Mercury 25 ppm	1.663	18.561	Designated by the Minister of Home Affairs	Yes
Aburatsu	Horikawa canal	organic matter	I.L. 20%	18	187	"	No
Ootake	Kojima	"	"	291	2.007	Ootake Area Environmental Protection Control Program	Yes
Omuta	Oomuta river Hakuti	Normal hexane extract Mercury Cadmium	Mercury 25 ppm Cadmium 200 ppm "	363 100 (N.2) 363 100 (N.2)	6.142 3.781 2.361	Oomuta Area " " "	 Yes Yes
Otaru	shikinai	organic matter	undecided	20	213	Designated by the Minister of Home Affairs	No
Rumoi	Fukukoo	organic matter	I.L. 15%	15	80	"	"
total				22.018 100 (N.2)	110.639	—	—

Notes: 1. As regards the standard for removal, the figures in excess of those given are to be removed.

2. In the Port of Omuta, part of the polluted sediments are to be treated by earthing to a total of 100,000m^3.

Table 3: Development of the Port Pollution Control Works
(works concerning polluted sediments treatment)

Fiscal year	1972	73	74	75	76	77	78	79	80 (provisional)	total
Cost (million yen)	3.256	3.656	6.948	8.188	5.678	6.880	6.742	7.792	6.152	55.292
Number of ports covered	6	11	14	12	12	14	13	14	13	

Table 4: Port Pollution Control Works Fiscal 1980 Work Plan (polluted treatment)

Port.	Cost	Volume of treatment.
Tokyo	1,440 million yen	2270 thousand yen
Yokohama	150 〃	68 〃
Nagoya	295 〃	11 〃
Yokkaichi	603 〃	49 〃
Osaka	702 〃	164 〃
Himeji	300 〃	34 〃
Hachinoe	432 〃	141 〃
Tsu-Matsuzaka	582 〃	146 〃
Tagonoura	188 〃	75 〃
Amagasaki Nishinomiya Ashiya	200 〃	56 〃
Higashiharima	30 〃	3 〃
Minamata	930 〃	69 〃
Omuta	300 〃	11 〃
total	6.152 〃	1.043 11 〃

Note: Dredging volume is a converted quantity.

In the port of Omuta the figure of 11,000m^2 shows the area of earthing.

Table 5: Implementation design surveys for Marine Environment Improvement Pilot Projects (fiscal 1979 and 1980)

Unit: million Yen.

Waters		Fiscal 1979	Fiscal 1980
Seto Inland Sea	Osaka Bay	150	150
	Hiroshima Bay	150	200
	Suoonada	-	50
Ise Bay		-	100
total		300	500

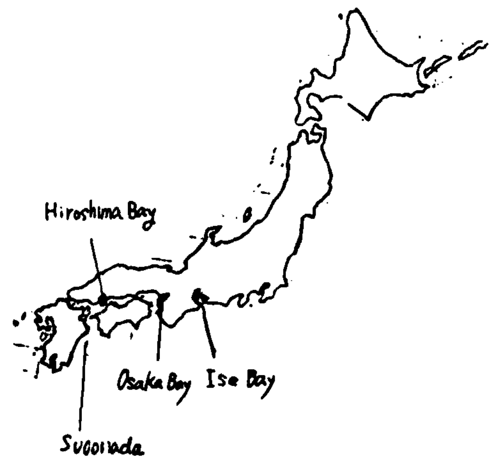

Fig. 1: Location map of implementation design surveys for Marine Environment Improvement Pilot Projects.

CURRENT ISSUES IN WATER POLLUTION CONTROL ADMINISTRATION IN JAPAN

TOSHIKI OSHIO

Environment Agency

Government of Japan

1. CURRENT STATE OF POLLUTION IN JAPANESE WATERS
2. WATER POLLUTION IN SEMI-ENCLOSED COASTAL WATERS AND AN AREAWIDE POLLUTION LOAD CONTROL SYSTEM
3. EUTROPHICATION OF LAKES AND RESERVOIRS
4. INTEGRATED APPROACH TO EUTROPHICATION CONTROL
5. CURRENT STATE OF BOTTOM DEPOSITS CONTAINING MERCURY AND PCB

1. CURRENT STATE OF POLLUTION IN JAPANESE WATERS

Although still very far from a satisfactory state, an overall improvement of water quality may be noted in Japanese waters in recent years. Let me start by examining the pollutants for which environmental water quality standards have been established under the provisions of the Basic Law for Environmental Pollution Control. As regards toxic or harmful substances relating to protection of human health such as cadmium, mercury, and PCBs, the ratio of samples exceeding the respective standards to the total number of samples taken has continued to decline over the years. (See Table 1.)

Table 1. Ratio of Samples Exceeding Water Quality Standards Relating to Protection of Human Health To The Total Number of Samples Taken

Substances	Water Quality Standards	1970 (%)	1975 (%)	1979 (%)
Cadmium	0.01 ppm	2.8	0.31	0.13
Cyanide	N.D.	1.5	0.02	0.01
Organic P	N.D.	0.2	0	0
Lead	0.1 ppm	2.7	0.32	0
Cromium (VI)	0.05 ppm	0.8	0.02	0.01
Arsenic	0.05 ppm	1.0	0.24	0.16
Total Mercury	0.0005 ppm*	1.0	0**	0**
Alkylmercury	N.D.	0	0	0
PCBs	N.D.	–	0.38	0.05

(* Annual averages; ** In number of sampling sites)

Among a number of substances and items for which there exist water quality standards relating to the preservation of our living environment, taking BOD levels in rivers for example (See Table 2), a general trend toward improvement may again be noted here. The non-compliance rate, however, is high among small rivers and streams flowing through large urban districts. The rate of achievement of environmental standards in 1979 was:69% for water bodies belonging to Category AA, 75% for Category A,60% for

Category B, 46% for Category C, 56% for Category D, and 41% for Category E, with an overall achievement rate of 65%.

Table 2. Ratio of Samples Exceeding Water Quality Standard for BOD in Rivers

Water Quality Categories	Water Quality Standard for BOD	1971	1975	1979	(Number of Water Bodies)
AA	1 ppm	36.7	31.4	23.9	(287)
A	2 "	30.9	24.4	21.5	(1002)
B	3 "	35.6	27.4	28.1	(497)
C	5 "	39.9	42.6	43.4	(227)
D	8 "	52.8	37.8	36.5	(81)
E	10 "	70.2	49.7	43.5	(142)

Taking for another example the number of coliform groups, one would get a non-compliance rate of 79% for all water bodies in Category AA (the standard is less than 50 MPN/100 ml), 73% for Category A (ditto, less than 1,000 MPN/100 ml), and 61% for Category B (ditto, less than 5,000 MPN/100 ml). No improvement can be seen in this respect.

Turning next to COD levels in coastal waters, a general trend for improvement may again be recognized, but the rate of achievement in 1979 was: 64% of water bodies in Category A, 82% in Category B, 99% in Category C, with an overall achievement rate of 78%. The rate was particularly low in the "enclosed" or "semi-enclosed" bodies of water. (See Table 3)

Table 3. Ratio of Samples Exceeding Water Quality Standard for COD in Coastal Waters to the Total Number of Samples Taken

Water Quality Categories	Water Quality Standard for COD	1971	1975	1979	(Number of Water Bodies)
A	2 ppm	38.5	19.6	17.4	(222)
B	3 "	30.5	18.3	17.1	(193)
C	8 "	15.2	7.4	4.7	(117)

Looking at COD levels in lakes and reservoirs, here again one may note an overall trend for improvement, but the actual rate of achievement of water quality standard is extremely low, as illustrated by the achievement rates of 24% of water bodies in Cagetory AA, 56% in Category A, only 7% in Category B, with an overall average rate of 42%. (See Table 4)

Table 4. Rate of Achievement of the COD Standard for Lakes and Reservoirs

Water Quality Categories	Water Quality Standard for COD	1971	1975	1979	(Number of Water Bodies)
AA	1 ppm	13.9	62.0	73.5	(21)
A	2 "	79.4	69.4	56.8	(57)
B	3 "	91.8	84.6	74.2	(14)
C	8 "	–	40.7	70.8	(1)

2. WATER POLLUTION IN SEMI-ENCLOSED COASTAL WATERS AND AN AREAWIDE POLLUTION LOAD CONTROL SYSTEM

In the three metropolitan regions of Tokyo Bay, Ise Bay, and Seto Inland Sea lives 53% of the total population of Japan, and 65% of manufactured goods are produced by these regions. As naturally to be expected, a large amount of pollutants is discharged into these so-called "enclosed" water areas. The flushing rate, or turnover of water with the outer fringes of the ocean, is very small, and organic substances are easily retained and accumulate in these water bodies. Due to the great influx of nutrients, moreover, the process of eutrophication is in rapid progress. As a result, the water pollution problem for these waters is getting worse and more complex every year.

In order to cope with this worsening progress of water pollution, the 84th session of the National Diet in 1978 enacted a Special Measures Law for Seto Inland Sea Environmental Preservation and amendments to the Water Pollution Control Law, both of which went into effect in June 1979. With the objective of achieving and maintaining environmental water quality standards, the new Law and the amendments of 1978 introduced a system of measures aimed at an "areawide control of water pollution load", which sought to cut down on the amount of total pollutant loadings into the three water areas in an effective and integrated manner, from all sources including domestic households and hydraulic load of rivers in upstream inland areas.

Targeted reduction in COD load (according to the type of sources and to each prefecture), goals for raising the percentage of sewered population, basic guidelines on setting new effluent control standares, etc., were to be specified in a comprehensive Pollutant Reduction Plan. The Plan was approved by the Prime Minister in March 1980, which set a deadline of 1984 for reducing the COD loadings to the levels shown in Table 5.

Table 5. General Features of Tokyo Bay, Ise Bay, and Seto Inland Sea regions and the Goals for Reduction of COD Load

	Tokyo Bay	Ise Bay	Seto Inland Sea
Surface Area of Water Body (km^2)	1,400	2,300	23,000
Volume of Water ($\times 100$ million m^3)	540	460	7,330
Population (1976) ($\times 1{,}000$)	22,200	9,090	28,130
Manufactured Goods (1976) (trillion yen)	32.2	18.4	44.5
COD Loadings in 1984 (target) (tons/day)	660	426	1,283
Domestic Sources	386	179	517
Industrial Sources	180	208	666
Others	94	39	100

In this connection it is important to note that expanding sewerage networks is an essential requirement for the achievement of these goals, as indicated by the still very low rate of sewered population in these regions: in 1977, it was 38% in the Tokyo Bay region, 27% in the Ise Bay region, and 31% in the Seto Inland Sea region.

Along with reduction of COD loadings, inflow of nutrients must be controlled so as to reduce production of organic material by phyto-planktons utilizing those nutrients. In 1977, for example, 24% (680,000 tons) of all fishery products in Japanese coastal waters was raised in the Seto Inland Sea. The number of "red tides" observed in the Sea, which was 48 in 1967, jumped from 79 in 1970 to 320 in 1975 and 165 in 1978. The red tides along with them brought heavy damages to fishery production in the Seto Inland Sea, and became an important issue to be urgently tackled.

In the face of this event, measures were taken under the Provisional Law for Seto Inland Sea Environmental Preservation to reduce by 1976 the COD loadings from industrial sources by more than one half of 1972 levels. The overall rate of achievement of water quality standards was 75% (40% foı Category A, 80% for Category B, and 98% for Category C). Compared with national averages, the achievement rate of water bodies in Category A, which make up a major part of the Inland Sea, is very low.

Furthermore, daily inflow of phosphorous into the Seto Inland Sea reaches as high as 81 tons per day (34 tons from domestic sources, 33 tons from industrial sources, and 14 tons from other sources).

In order to raise the water quality of the Seto Inland Sea, the Special Measures Law for Seto Inland Sea Environmental Preservation provides for measures to reduce the input of nutrients into the Sea area. On the basis of this Law, Director-General of the Environment Agency, in July 1979, directed the governors of relevant prefectures to draw up plans, including specific measures, to reduce or maintain the present level of P loadings into the Sea by 1984, depending on the prevailing state of pollution by the nutrient. Further studies will be conducted regarding possibilities for reduction of P concentrations in Tokyo and Ise Bays.

3. EUTROPHICATION OF LAKES AND RESERVOIRS

Of the 93 lakes and reservoirs for which water quality data are available, 54 show a pH of 8.5 or above, and a DO of more than 10 ppm. In these lakes, pH rises as CO_2 is taken up by the multiplying population of algae, and DO increases to the extent it becomes super-saturated. Many of the lakes and reservoirs have thus become enriched with nutrients. Lake Suwa, for example, had a nitrogen concentration of 0.26 ppm and phosphorous concentration of 0.02 ppm in 1931, whereas the corresponding figures rose to 3.51 ppm and 2.47 ppm, respectively, in 1978.

It should also be noted that Japanese lakes, many of which are still in an oligotrophic state and have long been associated with one of the greatest transparencies in the world, are rapidly deteriorating in terms of their clarity/ transparency. Secci depth of Lake Shikotsu, for example, decreased from 25 meters in 1925 to 18.7 meters in 1978, while in Lake Towada it was reduced from 20.5 meters in 1930 to a mere 9.8 meters in 1978. The phenomenon of lake eutrophication is not restricted to natural lakes, either. It now extends to many of the man-made reservoirs constructed for drinking water purposes. Of a total of 132 revervoirs surveyed in 1979, 55 are reported to have suffered cases of fungus-like odor and taste in the water. In other cases, filters were clogged by mass populations of algae and filtering efficiency was lowered.

4. INTEGRATED APPROACH TO EUTROPHICATION CONTROL

In order to facilitate adoption and implementation of comprehensive measures to control eutrophication, Environment Agency decided to establish a set of "water quality objectives" for phosphorous and nitrogen, and in December 1979 convened a group of experts to consider and recommend appropriate levels of water quality regarding nitrogen and phosphorous with a view to controlling, and wherever possible preventing, the progress of eutrophication in the nation's various enclosed or semi-enclosed waters. The group is expected to finalize its recommendations by the summer of 1980 as far as the water quality objective for phosphorous levels in lakes and reservoirs is concerned. The objectives for P concentrations in other areas and those for nitrogen are expected to take much longer to materialize.

In March 1980 the Environment Agency also announced its plans for developing an integrated approach to eutrophication control, which included, among other things, an appeal to all government ministries and agencies to refrain from using phosphate-containing detergents at their organizations and affiliated institutions, including public schools and government-run hospitals and clinics. Notable among other measures to be taken were: accelerated deployment of sewerage networks, ensuring appropriate maintenance of individual household septic tanks, management of farming practices, mitigation and recycling use of wastes from dairy industry, further research into methods of control of non-point sources, development of technology for advanced waste-water treatment, etc.

5. CURRENT STATE OF BOTTOM DEPOSITS CONTAINING MERCURY AND PCB

In 1973, the contamination of the public water bodies caused by such persistent chemical substances as organic mercury, which caused poisoning among the inhabitants of Minamata and Niigata, attracted the public attention even further when illness among the inhabitants of the Ariake Bay area was also suspected as being caused by organic mercury poisoning.

A nationwide comprehensive environmental survey was conducted of fishery products, water, bottom deposits, soil, and agricultural products in areas where fishery products were reported contaminated by a high concentration of mercury by investigations conducted during the years prior to 1973 and in those areas adjacent to mercury handling factories and mercury mines. As a result, the bottom deposits taken from 27 water areas, consisting of 16 rivers and 11 bays, were found to contain mercury in excess of the provisional control value established on August 31, 1973.

As of January 1979, bottom deposits in 42 water areas had been found contaminated by mercury in excess of the provisional removal standards (27 of them were found by the surveys conducted in fiscal 1973 and 15 additional areas by subsequent investigations). Of these, removal works of bottom deposits were completed in 33 water areas; similar works are under way in 6 water areas; plans are being drawn up or detailed investigations are under way in 3 water areas.

From the same standpoint taken with respect to mercury pollution, provisional standards for the removal of PCB-contaminated bottom deposits were established on Feb. 28, 1975.

As a result of investigation, bottom deposits in 69 water areas (51 of them found in the investigations conducted in fiscal 1973 and 18 of them in other surveys) were found to contain PCB in excess of the provisional removal standards.

Of these, projects for the removal of the contaminated bottom deposits were completed in 54 water areas and are under way in 3 water areas; projects are being planned or detailed investigations are under way in 12 water areas.

DEMONSTRATION OF ADVANCED DREDGING TECHNOLOGY DREDGING CONTAMINATED MATERIAL (KEPONE) JAMES RIVER, VIRGINIA

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ABSTRACT

A demonstration project to be conducted on the James River, Virginia, will compare the efficiency, plant output, and environmental advantage of dredging contaminated material with a typical hydraulic dredge equipped with a cutterhead and a dustpan head. The comparison of the two excavating methods (heads) will be conducted under controlled conditions in the maximum turbidity zone of the river, where channel sediments are laced with the insecticide KEPONE. The project will entail the conversion of a typical cutterhead dredge to a dustpan dredge. The dustpan dredge will be equipped with necessary control cables for maneuverability in a tidal estuary and the head will be appropriately modified to effectually skim dredge the 18-inch to 24-inch layer of polluted sediment. Dredging will be conducted in selective areas, continually monitored with both on-board and off-dredge instrumentation, and the dredge and head accurately positioned at all times. Environmental monitoring will be conducted around the dredge and at the discharge. Following the excavation by dustpan, the dredge will be re-converted to the cutterhead mode and the test dredging conducted in comparable areas under identical conditions. The purpose of the project is to demonstrate that equipment, readily available in the United States, can efficiently excavate toxic "hot spots" from the nation's channels and harbors; that total containment of the pollutant is possible; that secondary turbidity release can be minimized; that the material can be removed at in situ density; that containment problems at the disposal site can be significantly reduced; and that the clean-up effort can be accomplished at a reasonable cost. It is further believed that the demonstration project will yield applied technology that will benefit the dredging industry and environment. Studies and recommendations from the Dredged Material Research Program will be given site specified application; the effectiveness of on-board instrumentation and accurate positioning of the dredge and the head will be established; the impact of the variableness within the dredging effort itself will be determined; and the advantages of several specific discharge configurations will be investigated.

INTRODUCTION

The James River is located on the east coast of the United States. It has its beginnings in cold, clear mountain streams deep in the State of Virginia. It is unnavigable above Richmond, but below the state capitol it provides for some 90 miles of deep draft channels and connects Richmond with the port of Hampton Roads, at Norfolk, Virginia.

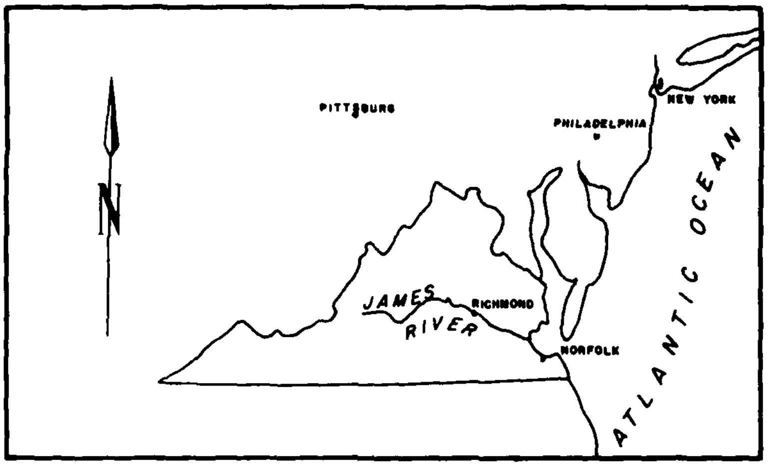

Figure 1 - Location of the James River, Virginia

The upper reaches of the navigable river from Hopewell to Richmond are lined with modern industry that depends on the river for the transport of material necessary to their survival. Unfortunately, the industry has had its accompanying impact on the river environment. Perhaps, the most famous--or infamous--is the Allied Chemical Corporation semi-works plant at Hopewell.

Figure 2 - Allied Chemical Corporation

The Allied Chemical Corporation developed a product in the early 1950's to control ants and roaches. They produced and marketed the product at Hopewell from 1967 to 1974 under the registered trade name of KEPONE, a member of the cyclodiene family of insecticides. Most of the KEPONE was exported for use in the Caribbean and Central American banana fields, and in other countries for the control of potato beetles. Another company, Life Science Products, under contract to Allied Chemical, began producing the insecticide in 1974 and continued production until closure of the plant in September 1975. During the period of 1967 to 1975 about 3.3 million pounds of KEPONE were produced. It is estimated that as much as 65,000 pounds of this amount (about 2%) was discharged into the James River system.

KEPONE can have serious effects on humans. For example, more than 70 employees of the Life Science Products were diagnosed to have KEPONE poisoning. The resulting ailments ranged from slurred speech, loss of memory, irritability, and sleeplessness to liver damage and sterility. Concerned about the accummulative impact of prolonged exposure to the insecticide and to guard against widespread poisoning, Mills E. Godwin, Jr., then Governor of Virginia, ordered the James River closed to the taking of fish on 18 December 1975. The river remained closed to recreational fishing until September 1980.

Even though the KEPONE alarm appears to be abating, the problem of extreme pollution of our waterways and harbors remains of critical concern. What would we do if a dangerous toxic should be inadvertently placed in Norfolk Harbor? What dredge plant is best suited to toxic removal? Which plant types are available? Of those available, under what conditions do they best control secondary pollution release? What about disposal? and on and on!

Our experience with KEPONE, if it has done nothing else, has focused our attention on alternatives and technology to best remove pollution "hot spots" should this need occur. We do not want to be in the position of having to experiment with highly toxic materials. If and when such a disaster occurs, we want to know what our options are and what the impact of the individual options will be. To that end, we proposed to compare readily available plant or equipment under controlled conditions, to document efficiency, to monitor turbidity, and, also of importance, to establish reliable cost parameters. Above all, we want to develop a system, a technique, a technology, that will allow the effective use of existing industry equipment, appropriately modified.

DREDGES

In February 1979, after an evaluation of dredging technology on the world market, the Norfolk District recommended to higher authority that a conventional hydraulic cutterhead dredge, and a type of dredge new to the United States, be tested to compare their efficiency and environmental advantages. At that time, the new type of dredge recommended was the Japanese Oozer dredge, which was reputed to be highly suited for clean-up operations.

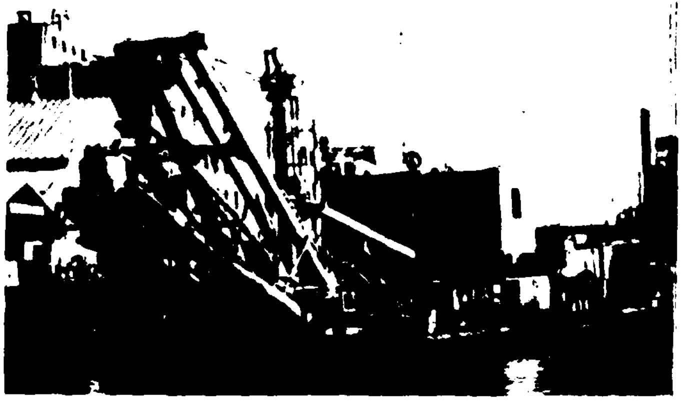

Figure 3 - Oozer dredge

Since then, we have come to believe that a dustpan dredge, a type used in the United States on the Mississippi River, could equal the efficiency of the Oozer and be better suited for the dredging test - of major importance is that it is of a type readily available and adaptable to cutterhead operations. The decision was made to test the cutterhead and the dustpan to determine their respective advantages for removing contaminated sediments, within 18 to 24 inches of the surface, over very selective areas. The test would investigate different methods of dredging with the aim of minimizing dredge-induced turbidity and achieving maximum containment of the contaminated silt at or near in-place density.

The test itself will take place on the James River in the zone of maximum turbidity.

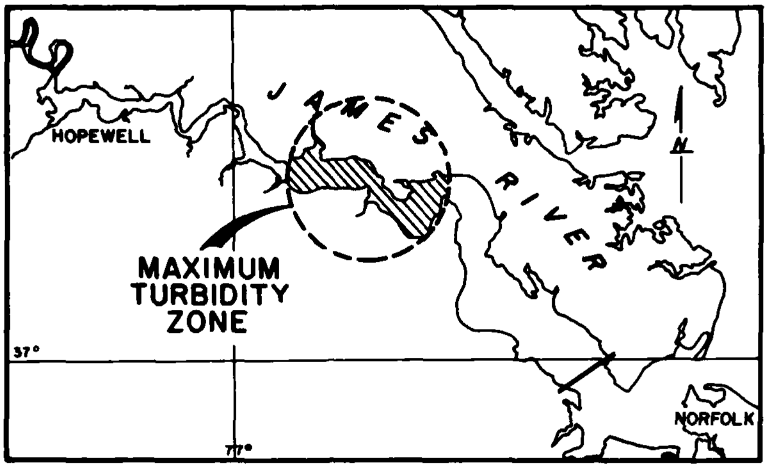

Figure 4 - Test Area: Zone of maximum turbidity

Within this zone, the fine sediments exist in three states.

a. Mobile particles - Suspended solids that move regularly in response to tidal circulations.

b. Static particles - Sometimes referred to as "fluid mud" or "fluff", this is the intermediate state between the mobile and the settled solids.

c. Settled silts - The "solid" soil formed by the consolidation of the static suspensions.

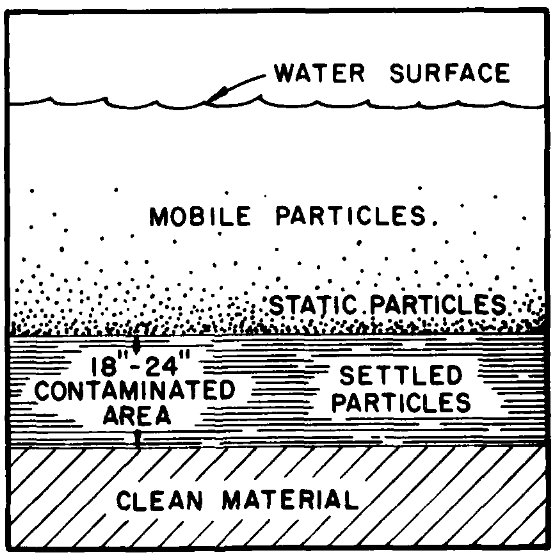

Figure 5 - Stages of sediment

The test is designed to detect difference in these states - particularly the mobile state - produced by the two dredging modes.

Cutter Suction Dredges

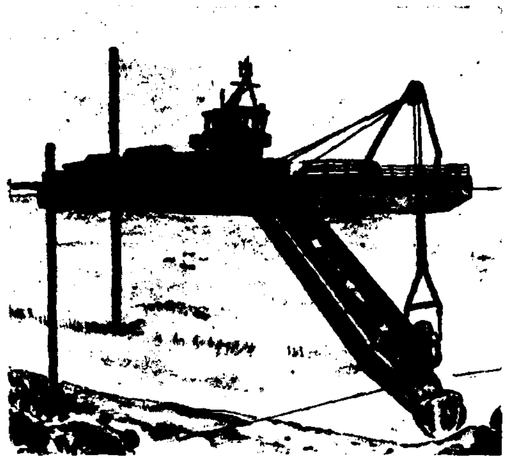

Figure 6 - Cutterhead dredge (from Hydroland)

The cutterhead suction dredge (radial cutting) would appear to be ideally suited for removal of contaminated silt within the greater Hampton Roads area, where an appropriately designed disposal area can be designated at Craney Island. For this application, the cutterhead dredge possesses the following advantages:

- Positive anchorage
- Accurate movement over the area to be dredged
- Positive excavation of cohesive soils (i.e., rotary cutter)
- Means of discharging materials over long distances
- Control of dredging depth
- Control of output (i.e., by variation of cutter and swing speeds)

The cutterhead suction dredge has some critical disadvantages where "total containment" of contaminated silts is desired:

- The rotational action of the cutter resuspends settled silts and creates high levels of turbidity.
- The cutter bulks the material, thus increasing the water content.
- The reduced output of solids due to bulking contributes to disposal area problems
- The geometry of the radial cut will result in the introduction of excessive dilution water by the overlap of swing arcs within the dredging area. This is best explained pictorially, assuming an optimistic swing arc and the use of a travelling digging spud rather than the more traditional "two fixed-spud" arrangement.

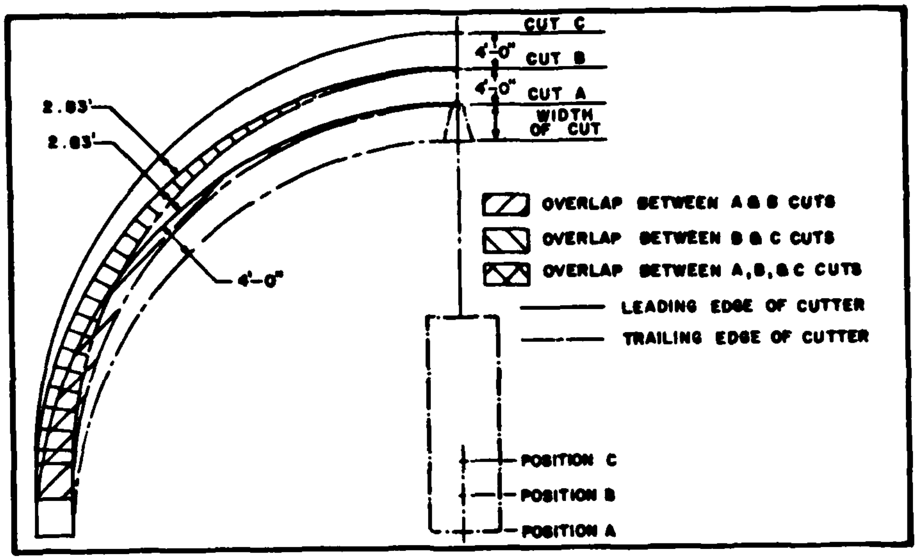

Figure 7 - Geometry of radial cut

Utilizing a conventional cutterhead of an assumed length of 4 units, the radial width of cut would be 4 units only on the first swings; thereafter, the width of cut over new material would vary from 4 units at the centerline to 2.83 units at an angle of 45 degrees. It can be readily seen that the more extreme the cut - that is, the greater the arc - the greater the introduction of dilution water. If a cutter suction dredge having "two fixed-spuds is used, the resultant cut will show considerable change and irregularity over the swing area contained within the "step ahead" angle.

The areas of overlap, having been previously excavated, would not have sufficient material bank to close off the ingress of dilution water. It is acknowledged that these shortcomings can be reduced by certain modifications, such as installation of a "shoe type" head or by the installation of a moveable skirt around the cutterhead. These adaptations will not be considered in this demonstration since we want to compare the advantages of an efficiently operated "cutterhead" with an efficiently operated "dustpan" head.

Dustpan Suction Dredges

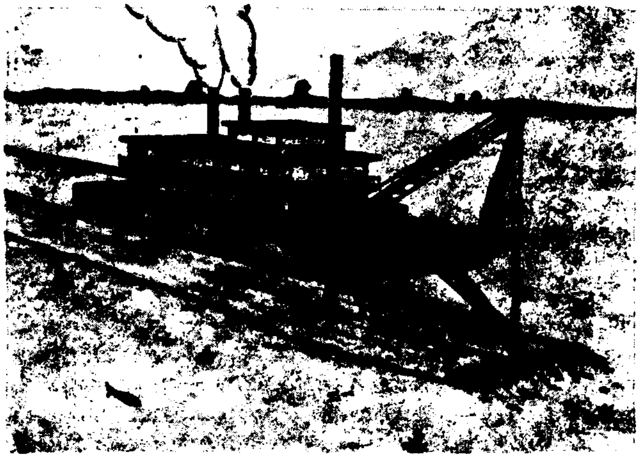

Figure 8 - Dustpan dredge

Whereas the cutterhead dredge swings, the dustpan operates on a "straight line" method utilizing maneuvering wires. Dustpan dredges were designed for high output in granular materials. High outputs are obtained by using a very wide head force against a bank of granular material. By injecting pressure water through nozzles at the "toe" of the slope, a continual collapsing face of material is created. The effect of bulking, caused by increased pore pressure, together with gravity creates a fluidized dredging zone at the entrance to the head resulting in very high outputs. A nominal rate of advance for this type head would be 300 feet per hour with approximately 20 percent solids being dredged. While the dustpan is adapted to work on the Mississippi River where sand sediments are excavated, it is believed that the dustpan has considerable advantages to offer when dredging contaminated silts:

- The straight line method of dredging
- Constant width of cut
- Constant dredging speed at constant winch speed
- Accurate control of dredging depth
- Maximized containment of material
- Reduced turbidity
- Near in situ density of material
- Reduced disposal area problems

The dustpan does have some apparent disadvantages when dredging contaminated silt in a tidal estuary:

- Dredging accuracy is difficult to control in soft materials
- Tidal fluctuations necessitate the use of stern anchors
- Water jets cannot be utilized since the material to be dredged has a water content of approximately 200 percent

- Possibility of choking in compacted cohesive material due to tapered inlet
- Velocity patterns over the head when dredging homogeneous suspensions under laminar flow will probably induce "plug flow" conditions, effectively reducing the width of head for dredging and causing "spills" over the outer ends of the dustpan head. This will be covered in more detail later.

A feasibility study was completed by Amalgamated Dredge Design, Inc., in 1980, which showed that it was practical to convert a conventional hydraulic dredge found in the Hampton Roads area to the dustpan mode of operation, test the efficiency and environmental advantages under controlled working conditions on the James River, and then convert the dredge back to the cutterhead mode and repeat the same tests. This feasibility study forms the basic scope of our proposed demonstration project.

The dustpan head, which will be used, will be removed from a decommissioned Corps dredge in St. Louis and modified for the purposes of this test. As noted earlier, the head normally employs water jets to loosen the coarse material. Since the material on the James is silt, the jets will be removed because they would cause excessive turbidity and add undesired dilution water.

A major advantage of the dustpan head over the cutterhead is the dustpan's ability to more accurately control the dredging depth and to theoretically skim off fine layers of contaminated sediments. This demonstration will employ state-of-the-art electronic positioning equipment to track both the location and depth of the dredge heads at all times. Monitoring devices will be maintained at the heads to document their respective effectiveness in turbidity control. In addition, other monitoring stations will be stategically established around the dredge to trace pollution release. Since the cutterhead action thrashes or flails the material, the obvious advantage of a dustpan heads is its ability to more gently direct the silts to the suction mouth. To that end:

a. The flow to the dredging head must be as uniform as possible. The velocity of material to the head and the velocity of the head through the material must be such that added water is not drawn into the head by too low a velocity through the material or that material is not spilled over the head by too high a velocity through the material.

b. The submergence of the head in the material must be such that the material will flow to the head under the influence of the hydrostatic head difference over the inlet. If this hydrostatic difference, controlled by the dredge pump speed, is too high for the submergence as set, then vortexes will form along the leading edge of the dredge head. These vortexes will introduce water into the head without entraining solids and thus reduce dramatically the density of the mixture being dredged. Figure 9 illustrates typical water velocities in the dustpan head, of the Corps' dredge JADWIN, established using a small-scale model at the Waterways Experiment Station.

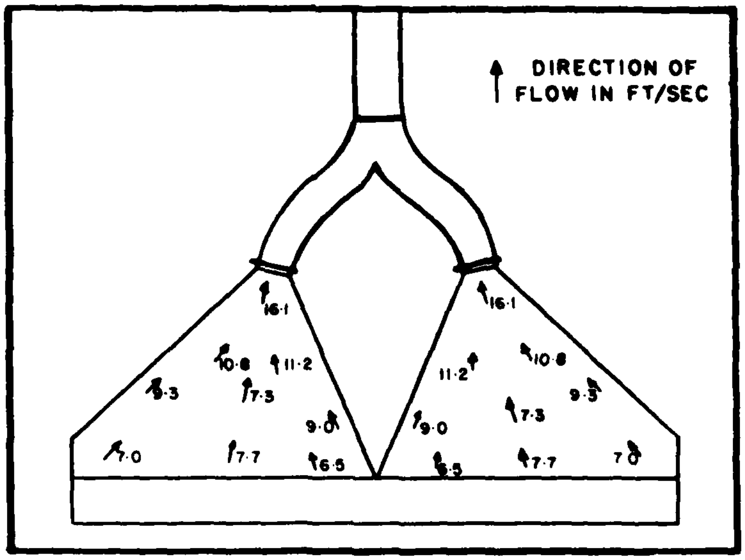

Figure 9 - Dustpan head (dredge JADWIN), water velocities

The effect of side wall friction is evident in these tests and this effect will also be present when dredging. Due to the higher viscosity of the dredged material and the probability of laminar flow, the possibility of plug flow along the center portion of each part of the double head is almost certain. This flow pattern could be modified by fitting splitters inside the head; these might need to be fitted after the preliminary dredging tests. In order to minimize the production of vortexes at the entrance to the dustpan head, an area between the double heads must be plated over and a "rollover" bar fitted across the full width of both heads.

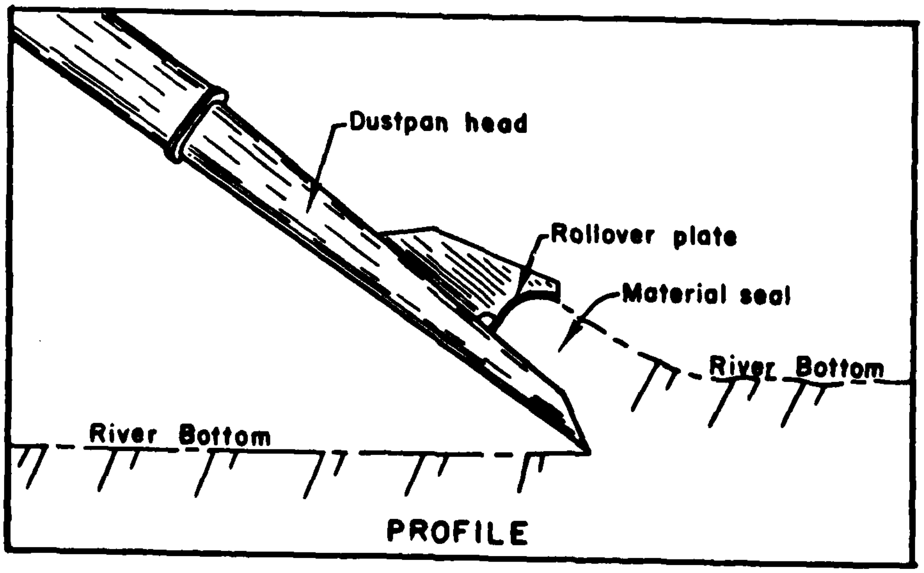

Figure 10 - Dustpan head with rollover bar

This rollover bar is a shaped plate designed to maintain the necessary head of material over the top edge of the mouthpiece and to prevent the spilling of material over the head by rolling the material forward on top of the existing deposit. The shape of this plate must be such that added turbidity is kept to a minimum and overspill is prevented.

As noted earlier, the test will be conducted on a large scale in the maximum turbidity zone in the river, where approximately 400,000 cubic yards is available to be removed. As well as comparing efficiency and output, the tests will attempt to maximize solids-to-water ratio of the slurry. Under this test, the material is to be deposited in overboard disposal sites. In addition to testing the dredging procedure, we also propose to monitor the disposal areas for the release of KEPONE in conjunction with State and Federal environmental agencies.

Following the dustpan test the dredge will be re-converted to the cutterhead mode. All tests will be re-run and comparisons drawn. Dredging is scheduled to be performed during the period September 1981 through February 1982. The total cost of the project is expected to be about $3.2 million, or roughly $1 million above the cost of a routine maintenance dredging operation.

Since one of the objectives of this demonstration will be to develop a system that will allow existing industry plant to be utilized in the clean up of pollution "hot spots", a major effort will be directed toward developing a modification "kit" that is adaptable to existing dredges. The kit, to be designed and built around a dustpan head, will ideally provide total containment at the intake and allow for accurate skim dredging of surface pollutants. In addition, the kit will provide the added dimension of selective dredging of stratified materials for a variety of disposal purposes. For example, the polluted surface material can be skimmed off and placed in a sealed disposal area. If necessary, the underlying silt could then be placed in another confined site or used to seal the pollutants; finally, any underlying sand could then be pumped to a storage site for later use or to an eroded beach.

CONCLUSIONS

I am extremely optimistic that the ability to transport silts at nearly in-place density will lead to innovative management techniques of both the dredging operation and the disposal site. I am particularly excited about how the information gained from this project can be used to benefit both the dredging industry and the environment. The effectiveness of on-board instrumentation, such as velocity and density meters, will be established by comparison with remote, off-board, monitoring devices. Also, the advantages of accurate location of the dredge and the dredge-head will be established. In addition, the impact of the dredging effort itself in all of its variableness and fluctuation will be evaluated. For example, how do the swing, the pump speed, and the cutter action interact to optimize efficiency and, at the same time, reduce environmentally detrimental impacts? Further, different discharge configuration will be employed throughout the demonstration and the impacts of the different disposal modes will be evaluated. The

demonstration project will involve site specific application of the studies and recommendations made by the Dredged Material Research Program and evaluated from operational, environmental, and economical vantage points. As a result, this project should hold meaningful application to the on-going dredging effort and related environmental concerns.

While this project primarily concerns dredging techniques and comparisons, I would also like to digress briefly to consider a series of actions taken to ensure that existing disposal sites in Hampton Roads will be available for long-term needs and adaptive to a variety of dredging methods. To that end, members of the Norfolk District are working with the Waterways Experiment Station to provide operational and management guidelines for Craney Island. These guidelines will be designed to:

- Maximize volumetric disposal capacity
- Dewater and densify fine-grained material to the maximum extent possible
- Reclaim and remove usable material, for both on- and off-site productive uses
- Maintain acceptable water quality of effluent
- Establish safe containment procedures, as necessary, for contaminated materials dredged under a variety of modes
- Abide by all legal and policy constraints

It is proposed that the technology developed through the Corps of Engineers' *Dredged Material Research Program* will be fully applied to the development of this management plan. The end product, as I see it, will be a set of concise and functional guidelines for the operation of the Craney Island Disposal Site for various dredging and disposal activities.

This is not meant to be an exhaustive report on the proposed demonstration project. Most certainly, the project will involve many aspects that I have elected to ignore in this paper - including:

- Methods and difficulties of removing the cutterhead and installing a dustpan head
- Installation of maneuvering wires
- Flow control considerations across the dustpan
- Inlet conditions at the suction
- Effects of vibration
- Instrumentation
- Sampling techniques

Rather, this has been a limited introduction to some of our concerns and a general overview of how we propose to address those concerns. A full report of our findings will be prepared following the demonstration. Most assuredly, a potential contamination problem exists. This project will demonstrate the effectiveness of a potential clean-up approach. I have often heard it said in connection with dredging that "it's what's up front that counts". We propose to conclusively document this truth with this James River test.

SOME COMMENTS ON DREDGING WORK IN JAPAN

February 1981

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Japan Dredging and Reclamation
Engineering Assoc.

SUMMARY

Under the recent circumstances of the general dredging work in Japan, the significance of dredging the residue of contaminated river and port bottoms has taken on importance, and intensive technical research in this field is now being carried out.

1. INTRODUCTION

In connection with providing for a better environment by disposing of harmful bottom sediments, a method by which the harmful bottom sediments are made harmless after being dredged is now more frequently employed than the method by which the harmful bottom sediments are simply confined in their original state. The dredging work for harmful bottom sediments has been carried out in the same way as the dredging work for general bottom material, although dredging of harmful bottom sediments has its own technological peculiarities. Accordingly, in order to know all the circumstances dealing with the dredging work for harmful bottom sediments in Japan, it is important for us to have a clear knowledge of laws and tendencies for all types of dredging works, including the dredging work of harmful bottom sediments.

In this paper, as well as the outline of the dredging work, a part of the author's research deals with the overlaying technique for disposal areas which is believed to be one of the most troublesome problems regarding the dredging technologies for harmful bottom sediments.

2. LAWS

2-1. Outline

Since Japan consists of numerous islands connected to each other in a narrow vertical band, it is referred to as the Japanese islands. Marine

transportation links the cities of these various islands and is the most important means of distributing materials. Also, as these islands possess a limited amount of raw materials, marine transportation is also important for the transportation of these much needed materials from overseas. The residents living on these islands cannot afford to improve their seaways and mooring basins to better facilitate marine transportation. Due to these circumstances, dredging work to clear the traffic channels has been on the increase.

The Japanese islands are covered mostly by steep mountains, with only a narrow portion of the land being flat and alluvial, this being formed by the rivers carrying the soils down from the mountainous areas. On this small amount of land, over a hundred million people live, and when the rivers overflow, the damage is extremely serious. In addition, due to the fact that people and factories are overconcentrated in these cities, the demand for the reclamation of sea areas has been on the increase. In this case, dredging work is indispensable to prevent rivers from overflowing and to reclaim land for production purposes. Furthermore, the dredging work is required to improve fishing ports which are the basis for the fishery industry in order to supply Japan with this much needed protein.

In this section, the matter of who should take the primary responsibility for dredging and also who should bear the expense necessary for dredging from the legal viewpoint is taken up.

2-2. Dredging work for the improvement of seaways and mooring basins

In an effort to provide for steady improvements and smooth operation of ports and harbors, and also to enable the timely development and maintenance of seaways located in the straits within the territorial waters, the Port and Harbor Law was enacted. The number of ports and harbors, based on the Port and Harbor Law, amounted to as many as 1,089 in 1979. Of these, 123 ports and harbors are major ports having a wide hinterland, and the remaining 966 are termed local ports. Each of these ports and harbors has respective water areas called port areas and their border lines are clearly specified. On the other hand, when seaways in the straits within the territorial waters require any developmental or conservatory works, the Government clearly states the sections of the seaways on the basis of the Port and Harbor Law. The Port and Harbor Law places the responsibility for administration of ports and harbors on the

local public bodies and also puts the responsibility for the developmental maintenance of the seaways not reverted to ports and harbors on the Government. The local public bodies that administer the ports and harbors are called the port management body. Dredging to maintain the waterways in good condition and to develop and improve the seaways and mooring basins within the port areas is considered, among others, as their major work. Also, if harmful bottom sediments should accumulate in the port areas, it is the job of the port management bodies to dispose of the harmful bottom sediments. The expense of dredging for improvement of seaways and mooring basins in the port areas is shared by the Government and the port management bodies for major ports, but the expense for local ports is, as a rule, taken care of by the port management body under a Government subsidy. The proportion of the expense to be charged to or subsidized by the Government is specified in detail by the Port and Harbor Law. The principle, in part, is as follows:

The expense required for dredging for the improvement of the seaways and mooring basins for major ports shall be borne 50 percent each by the Government and the port management body, and the amount to be charged to the Government must be decided by the Diet. On the other hand, as for the expense required for dredging for the improvement of the seaways and mooring basins of the local ports, an amount corresponding to less than 40 percent of the expense may be subsidized by the Government. In cases where private industries, such as oil refining plants, iron-making plants, power stations, etc., located in the port areas are in hopes of widening and deepening of the seaway and mooring basin, the port management body can carry out the work as a public works project, but the expense required is to be borne by the private enterprise who made the application for the work in accordance to the degree it benefits that industry. Also, the expense taken for the port management body to carry out dredging of harmful bottom sediments in the port area shall be borne by the person or party who produced harmful bottom sediments to the extent that it necessitates dredging.

As stated above, dredging for the improvement of ports and harbors is a service imparted to the port management body, but for major ports, the Government in the place of the port management body may carry out dredging when an agreement is reached between the port management body and the Government. This

leads us to interpret that the Government aids the promotion of dredging of the seaways and mooring basins by relieving the port management body and private dredging industry from great burdens such as the possession of expensive dredgers and highly advanced dredging technology.

2-3. Dredging work for seashore land reclamation

In Japan, the majority of the major cities have developed along the seashore, and various manufacturing plants are located in and around these cities, unceasingly requiring new land for expansion of their production activities. Also, the population of these cities is becoming more and more crowded, causing various urban problems. As countermeasures for these problems, the redevelopment of cities is being planned, and, in this connection, the development of new land along the seashore areas is being promoted. Thus, reclamation work along the water areas in contact with these cities is now under way including dredging projects of taking soil out of the seabed. For these reasons, dredging sometimes plays an important part in these types of land reclamation.

In those cases where seashore reclamation work is carried out for the purpose of redeveloping cities and securing land for industrial purposes is performed within the port area of major ports, the Government becomes of service by furnishing funds necessary for completion of the work in accordance with the Law for Promotion of Port Improvement. In short, the Law for Promotion of Port Improvement compensates for the Port and Harbor Law to make the harbors more efficient and easy to use, but the degree of aid given by the Government is limited since the benefits of such improvements are directly received by the users of such developed land.

There are numerous seashore land reclamation projects that do not benefit from the Law for Promotion of Port Improvement, including all the reclamation work executed in areas other than the port areas of major ports. Among these works are those which receive soil from the dredging projects. The Public Water-Area Reclamation Law applies to all such works. A person or party who engages in the reclamation business for sea areas must submit a plan to be licensed by the prefectural governor concerned. If there are no other parties having submitted plans to reclaim the said land and the plan submitted seems reasonable, the applicant can receive the license, but a person or party who has received the license has the responsibility for carrying out the reclamation

work in accordance with the submitted plan. Land development work of seashore areas that has been applied for under the Law for Promotion of Port Improvement is also subject to the Public Water-Area Reclamation Law. The areas for land to be reclaimed during the period 1945 through 1980 amounted to approximately 48,500 hectares; the land areas that have already received licenses but have not been reclaimed completely as of 1980 amounted to approximately 13,900 hectares. Several percent of soil to be supplied for the reclamation work is dependent on the dredging work.

2-4. Dredging works for the improvement of fishing ports

The improvement of fishing ports is performed in accordance with the Fishing Port Law. The Government specifies the general principles of the fishing port development plans, but improvement projects for individual fishing ports are carried out by the particular local public body. The number of fishing ports totalled 2,871 in 1980, each having a fishing port area based on the Fishing Port Law. As for the improvement projects for fishing ports, the expense required for dredging of seaways and mooring basins is partly shared or subsidized by the Government. The proportion of the share varies with the type of fishing port since fishing ports utilized by many fishing boats will be given from 60 to 80 percent of the necessary expense by the Government, whereas for the other fishing ports, the state subsidizes from 40 to 60 percent of the necessary expense.

The Fishing Port Law specifies not only work for improvement of fishing ports but also work for removing sludge deposited in the fishing port area.

2-5. Dredging work under the River Law

The River Law is a basic law by which rivers are controlled to prevent disasters due to overflows. Those rivers designated by the minister of the Ministry of Construction are called first-class rivers (the Ministry of Construction has responsibility for these rivers). Those rivers designated by prefectural governors are called second-class rivers (the prefectural governors take responsibility). These rivers are declared public property, requiring proper administration by the river administrators who have the responsibility for establishing a basic plan for the execution of the required work, in which the design high water levels and cross section at the main points of the rivers must be well designed and recorded so that a disaster due to an overflow can be

prevented. The river administrators must carry out the plan in such a way that the actual cross section of a river coincides with the design cross section, which is accompanied by the need for dredging work in the downstream area of a large river. The way of sharing the expense required for the administration of rivers is specified in detail in the River Law, in which the expense for first-class rivers is, in principle, charged to urban and rural prefectures. For first-class rivers, however, the urban and rural prefectures bear, as a rule, 50 percent of the expense required for administration of parts of the river within the district concerned, whereas for second-class rivers the Government is burdened with the responsibility for sharing a part (less than 50 percent) of the expense. Also, the expense necessary for the river administrators to carry out the dredging of harmful bottom sediments from the rivers is charged to that person or party who brought about the necessity for such work.

3. TENDENCY OF DREDGING BUSINESS

3-1. Outline

As has been seen already, the dredging business in Japan is looked upon as important since it indirectly supports the national economy, all the more as it assists Japan's economical side. Since the oil crisis of 1973, in which Japan made the transition from a rapid growth economy to a stable growth one, the dredging business has continued to grow with its character changing somewhat. It was during this period that the dredging of harmful bottom sediments came to the front. The tendency of the dredging business related to ports and harbors development is described below.

3-2. Change of dredging works for seaways and mooring basins

Table 1 gives the change in working expenditures during the period from 1960 through 1978. A marked reduction in working expenditures in 1976 was seen, delayed three years from the time of the oil crisis. Such a delay is understandable in view of the character of the dredging work for seaways and mooring basins. Since 1976 the working expenditures have tended to increase slightly, but the amount of work has actually been reduced to a considerable extent if the cost increase trend year by year is taken into account. The working expenditure in 1978 was only 0.84 times that of 1975.

Fiscal year	Dredging work expenditures (in millions of yen)		
	Within port area	Without port area	Total
1960	6,680	110	6,790
1965	14,966	2,869	17,835
1970	40,599	3,072	43,671
1975	56,155	8,299	64,454
1976	33,783	9,591	43,374
1977	35,765	10,009	45,774
1978	41,832	12,391	54,223

Table 1. Working expenditures for seaway and mooring basin dredging work

3-3. Change in seashore reclamation work

Table 2 gives the change in the seashore development business which is being subsidized by the Government through loans. Yearly reductions in the development of land are shown in Fig. 1, indicating that reductions began concurrently with the oil crisis of 1973 and that the land developmental business is more sensitive to economical factors than the seaway and mooring basin dredging business. Since, however, the seashore land developmental business allows for some improvement work of existing lands, the amount of dredging work (shown in Table 2) is not necessarily accurate. A rough estimate of the dredging work, however, may be represented by the values in Table 2.

Fiscal year	Working expenditures (in millions of yen)	Areas (hectares)
1973	230,900	3,182
1974	231,700	2,421
1975	247,000	2,118
1976	237,800	1,921
1977	246,100	1,823
1978	220,400	1,657
1979	216,200	1,602

Table 2. Seashore land reclamation work

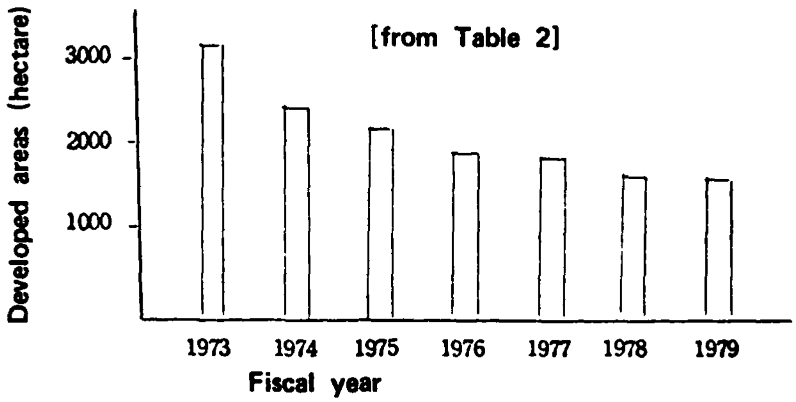

Fig. 1. Change in the area developed from seashore land reclamation work

3-4. Amount of dredging work for fishing ports and rivers

A six-year improvement works plan for fishing port facilities, from 1977 through 1982, has been put forward in which dredging work amounting to 134.2 billion yen and 23 million m^2 is in the process of being carried out; that is, approximately 20 billion yen worth of dredging work is being performed on a yearly average.

The exact amount of dredging work for control of the rivers is not clear, but is not a large percentage. According to the statistical data of the Ministry of Construction, the total amount of dredging work carried out during 1979 is as follows:

Total working expenditure	114.693 billion yen
Contract price	111.840 billion yen

The working expenditure contains the expense for dredging for improvement of the existing port facilities, including all expenses for private and small dredging work. This estimate indicates that the amount of dredging work for improvement of rivers is small.

3-5. Change in the achievements of the dredging industry

The Japan Dredging and Reclamation Engineering Assoc. is a body organized by the major dredging companies for the purpose of promoting dredging technologies. Most of the dredging work in Japan is carried out in the form of contract work by these companies. Figure 2 gives the change in the volume of dredged soils which was carried out by these companies during the 1959-1979 period,

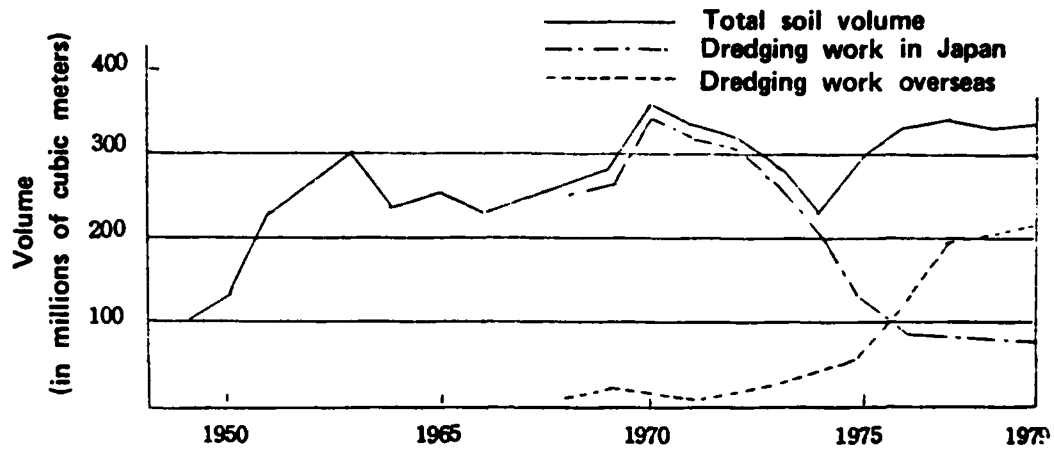

Fig. 2. Changes in the volume of dredged soils (by the 28 major companies)

showing that the volume of dredged soil amounting to as much as 300 million m^3 or more, which was formerly attained in Japan, fell drastically to 100 million m^3 in 1976, and there seems to be no prospect of returning to the former volume. The reduction trend in the volume of dredged soil started in 1971, two years preceding the oil crisis of 1973. This corresponds to the time when the chaotic development of lands for industrial purposes by reclamation began to receive criticism since it was causing many environmental problems. Figure 2 clearly shows the dredging industry moving to take up overseas work due to the insufficiency of dredging work at home.

3-6. Change in the number of dredgers

Table 3 gives a comparison of the number of dredgers possessed in 1978 with that in 1972.

Fiscal year	1972			1978		
Owners / Type of dredgers	Government and public agencies	Dredging industry	Total	Government and public agencies	Dredging industry	Total
Hopper dredger	5	1	6	5	1	6
Cutter suction dredger	49	383	432	27	352	379
Grab dredger	35	636	671	22	419	441
Bucket dredger	10	7	17	7	5	12
Dipper dredger	15	31	46	12	39	51

Table 3. Change in the number of dredgers possessed

The public agencies and the private dredging industry are both making efforts to reduce their number of dredgers due to Japan's transition from a rapid growth economy to a stable growth one.

The major types of dredgers used in the dredging industry in Japan fall into the cutter suction and grab dredger category, and the number of dredgers has decreased drastically for both types. In this connection, the average output of the main engine per one cutter suction dredger possessed by the dredging industry in 1978 was approximately 1,900 ps,* and also the average grabbing capacity per one grab dredger was approximately 4.5 m^3 in 1978. In the case of the hopper dredger, no change was observed. The number of hopper dredgers possessed by dredging companies was only one, having a capacity of 4,000 m^3.

Due to the above-mentioned circumstances of the dredgers, a large number of them are working in overseas areas, but their operation rate is still low. In an effort to develop technologies for dredgers specializing in dredging harmful bottom sediments, companies have been redesigning the dormant cutter suction dredgers.

3-7. Change in Government-executed dredging work

When an agreement is reached between the Government and the port management body in accordance with the Port and Harbor Law, the Government itself carries out the dredging of seaways and mooring basins of the ports and harbors. Also, the dredging work for seaways not belonging to ports and harbors and for the control of first-class rivers is carried out as Government-executed dredging work. A considerable part of the Government-executed dredging work is committed to the dredging industry in the form of contract work. However, the rest is performed by the Government itself by operating Government-owned dredgers. Table 4 gives the change in the volume of dredged soil under the above-mentioned direct execution of Government projects. Cases where the operation of Government-owned dredgers is entrusted to the dredging industry are rare in regards to rivers.

In the Ministry of Transportation, the following local branches for the

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* ps = pherde stark; ps = horsepower × 0.9863.

Fiscal year	Total
1970	7.23
1971	7.05
1972	3.67
1973	3.52
1974	4.33
1975	3.35
1976	3.21
1977	3.43
1978	3.07
1979	3.53

Table 4. Change in the volume of soil dredged by the Government-owned dredgers (in millions of cubic meters)

execution of Government-executed dredging work for seaway and mooring basins have been provided:

Name of branches				Locations
The 1st	District	Port Construction	Bureau	City of Niigata
The 2nd	"	"	"	City of Yokohama
The 3rd	"	"	"	City of Kobe
The 4th	"	"	"	City of Shimonoseki
The 5th	"	"	"	City of Nagoya

In these local branches, dredging work and construction work for breakwaters and quay walls are carried out. Sometimes, the dredging work for one port is assigned to both the Government and port management body. For example, the dredging work for the seaway of Yokkaichi port was performed by the 5th District Port Construction Bureau, but the dredging work for harmful bottom sediments deposited in the mooring basin was executed by the port management body.

The ratio of the Government-executed dredging work to the nation's total dredging work for seaway and mooring basins remains constant with respect to the latest trend, which is indicative of the maintenance of the present condition for the time being.

3-8. Dredging work in the future

Regarding future dredging work, a Governmental comparison for port improvements, for the periods of 1976 to 1980 and 1981 to 1985, was carried out and this comparison shows:

(Planned Period)	(Investment Cost)
1976 - 1980	3.10 billion yen
1981 - 1985	4.26 billion yen

In short, the investment cost for the newly planned 5-year plan for port improvements amounts to 1.37 times the previous 5-year plan. However, taking into account a possible cost increase for the coming five years, the real incremental rate of dredging work should drop to 1.0 times. This reflects the stringency of the Government's financial conditions in recent years. In light of the fact that the ratio of dredging work to improvement work for port facilities remains unchanged, it is foreseen that the amount of dredging work related to port improvements would be kept at the current low level for the present. However, it must be noted that the Government willingly cooperates with dredging work for the removal of harmful bottom sediments even for the next 5-year plan. The future outlook of dredging work to control rivers and also for improvements in fishing ports seems to have the same tendency as dredging work for improvement of port facilities, although detailed figures are not mentioned herein.

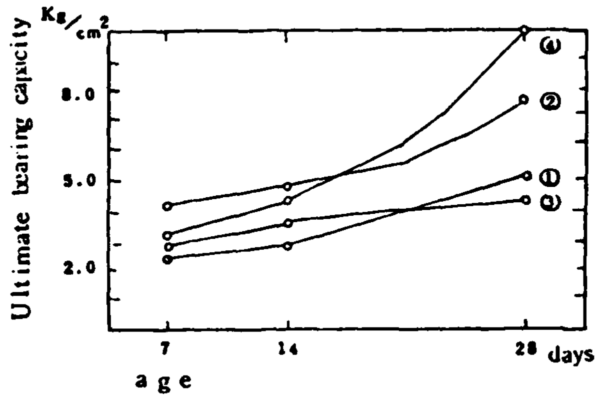
4. A STUDY ON THE MANAGEMENT TECHNIQUES FOR DREDGING SOIL

At the "U. S.-Japan Specialist Meeting on Disposal of Harmful Bottom Sediments" held in 1975[1)] and 1977[2)], the author presented Japan's techniques by which harmful bottom sediments are dredged and then treated. In the foregoing, the techniques which are used in Japan were discussed. In addition, an explanation of a technical study[3)] in which the author took part will be given to you so as to better understand Japan's disposal technology for harmful bottom sediments. Unless problems on how to manage the disposal of harmful bottom sediments already dredged are resolved, the dredging techniques for harmful bottom sediments should not be continued. The disposal of these sediments into the open seas is not allowed since they add to oceanic environmental pollution. Japan is a small country; there is no space available to dispose of these sediments. There is also an ever increasing demand for the development of lands by the

reclamation of seashore areas. Hence, the reclaimed lands are being watched with interest as disposal areas for dredged sludge. Reclaimed lands, however, are constructed for the purpose of utilizing them for industrial purposes, but the dredged sludge to be dumped into the reclaimed lands does not harden easily since most of it is composed of moisture and clay. That is to say, the dredged sludge is the most unsuitable material for reclamation purposes. However, there is no substitute place to dispose of this sludge. Hence, a method by which land for reclamation is embanked on all sides, sludge is dumped into the predetermined land, and a surface layer of soil is added to utilize the land is being carried out. However, when normal soil and sand are used as surfacing material, they settle into the sludge and its surface never hardens for any length of time, thus making the land unsuitable for use. For these reasons, the author has been concerned with an experiment in which a kind of light-weight powder can be used as the surfacing material. The author carried out an experiment and the procedures and results are summarized below.

The experiment was conducted at a reclamation site at Yokkaichi port. At the time of the experiment, approximately 5 meters of thick soft sludge was deposited in the reclamation site to the extent that one could not walk on the site. The experiment for the overlaying work was conducted by dividing a corner of the reclamation site into about a 700-m^2 section. For the material to be overlayed, a particularly light-weight granulated slag was employed. The slag, manufactured by quickly cooling blast furnace slag in its molten state by jet water, is light in weight as shown by its bulk density of 1.10 g/cm^3 when its moisture content is 9.68% and has a texture that becomes hard when mixed with a small amount of Portland cement. In this experiment, the granulated slag, to which was added 1 to 3% of Portland cement, was spread over the surface of the mud of the reclamation site at a thickness of from 60 to 80 cm by means of a conveyor. A plate load test was carried out to observe the effects. Figure 3 shows the results. The surface reached such a magnitude that it could withstand the passage of vehicles. Also, knowledge regarding the thickness of the overlay, the amount of Portland cement to be used, the effects of sheets, etc., was obtained.

Although an actual project using granulated slag has not yet been carried out due to the expense of the slag, the results of the experiment demonstrate the advantages of using slag. Also, if cheaper and lighter weight materials



	Thickness	Cement	Sheet
①	60 cm	1.0 %	Covered
②	80	1.0	Covered
③	60	3.0	Non Covered
④	80	3.0	Non Covered

Fig. 3. Plate load tests on overlaid grounds

could be found, the disposal of dredged sludge containing harmful substances could be performed more efficiently.

5. CONCLUSION

The dredging work in Japan has aided Japanese companies economically. Although, in recent years, problems have arisen such as the gradual reduction in the amount of dredging, the role of dredging contributions to the national economy should not yet be dismissed. The fact that there are new types of dredging techniques being devised to take care of the harmful bottom sediments, and that the dredging industry is making an all-out effort through research is an encouraging sign and deserves appreciation.

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UPDATE ON RESULTS OF LONG-TERM MONITORING OF DREDGED MATERIAL RESEARCH PROGRAM FIELD SITES AND VERIFICATION STUDIES

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ABSTRACT

The Corps of Engineers Dredged Material Research Program (DMRP) was completed in 1978. Since 1978, DMRP open-water disposal and habitat development field sites have been monitored to evaluate the longer term effects of disposal and behavior of the habitats. In addition, studies have been under way to verify and refine engineering or operational procedures developed during the DMRP for confining dredged material. This paper describes the studies and, where possible, presents preliminary study results for approximately three years of effort.

INTRODUCTION

The Corps of Engineers Dredged Material Research Program (DMRP) was successfully completed in March of 1978 (1,2). The five-year, $33 million study addressed critical questions concerning the environmental impact of dredged material disposal, and the results provided methods of minimizing any adverse effects. Since the DMRP was of a relatively short length (five years), it was not possible to evaluate the longer term effects of dredging and disposal or to verify and refine operational or engineering procedures for confined disposal of dredged material developed during the program. A significant portion of the five-year effort was consumed by the necessary program development and logistical planning always involved in large-scale field studies. This meant that many field sites were monitored for less than two years after disposal, which was not long enough to allow the sites to stabilize. It became apparent that continued monitoring at selected aquatic or open-water disposal sites and habitat development field sites would be necessary to better evaluate any longer term effects. Also, as is necessary after development of any new predictive procedures, field studies are required to verify and refine the relationship between predicted and observed behavior.

To meet the above-stated requirements, in 1978 the Corps initiated monitoring at selected field sites and began field and laboratory studies to verify and refine operational and engineering procedures (Figure 1). These and other related efforts (3) are currently being

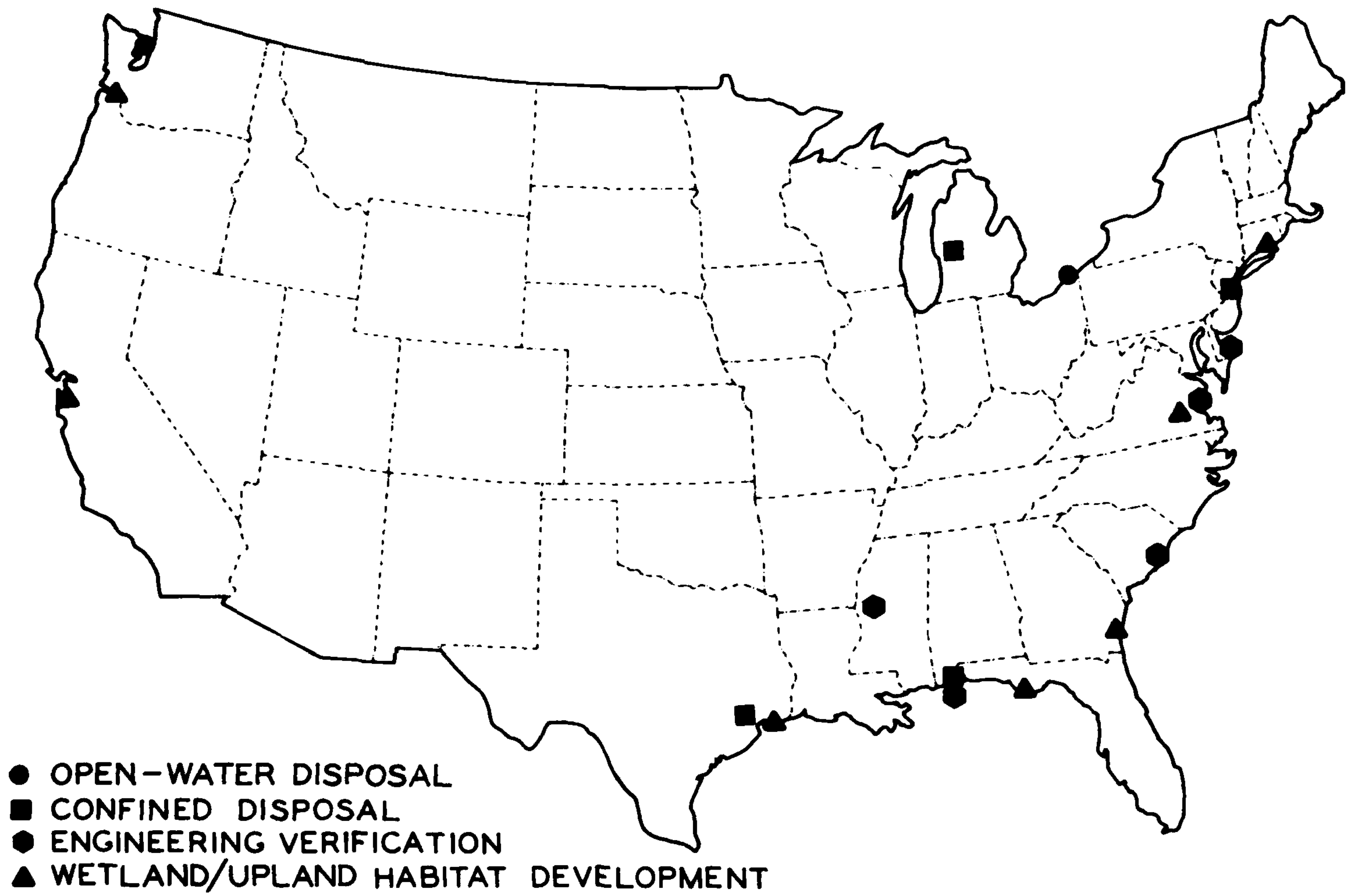

Figure 1. Field study sites under the Dredging Operations Technical Support Program

managed at the U. S. Army Engineer Waterways Experiment Station under the Dredging Operations Technical Support (DOTS) Program. This paper contains detailed descriptions of these studies and, when possible, gives study results after approximately three years of activities. In some instances, the activities will continue for the next few years. Therefore, any results must be considered preliminary.

Notations and units used in the various sections of this paper are those commonly used in the United States by the respective engineering or scientific discipline.

OPEN-WATER SITES

DMRP Studies

Field sites were chosen based on previous use of the site for dredged material disposal, availability of background data and logistical support, and site characteristics that were representative of other disposal sites. Five sites were studied during the DMRP and two were chosen for further investigation under DOTS. Two reports, which summarize previous information and data gathered during the DMRP at these two sites, are available (4,5).

Approximately 327,000 cu yd of dredged material was deposited from a hopper dredge at the Lake Erie disposal sites during 1975 and 1976. Approximately 30 percent of the disposed material was transported away from the study area; depth of the deposited material was generally <0.5 m. Impacts upon mobile pelagic biota were minimal while impacts upon benthic organisms were of a physical nature and were influenced by the transport of benthic organisms with the deposited dredged material. There was no evidence of uptake of heavy metals by fish or benthic macroinvertebrates at the disposal site. Chemical impacts on the water column were observed but generally lasted <2 hours.

Approximately 114,000 cu yd of Duwamish River sediment was deposited at the Elliott Bay disposal site in February and March 1976, creating an uneven mound of dredged material as high as 2.5 m at the center of the site. Levels of polychlorinated biphenyls (PCBs) in the deposited material were higher than in the disposal site sediments. This difference was used to track the movement of deposited material during the DMRP study period. There was some evidence of outward movement during the 9 months after disposal. Again water column animals were not adversely affected by the operation, and there was no evidence of heavy metal uptake. Benthic populations at the center of the disposal site were affected adversely; however, a number of benthic species were actively recolonizing the site 9 months after disposal.

DOTS Studies

Sites chosen for continued monitoring under DOTS were a freshwater site in Lake Erie off Ashtabula, Ohio, and an estuarine site in Elliott Bay, a part of Puget Sound, off Seattle, Washington.

Lake Erie Site

Work at the Lake Erie site began in August 1979. During a 2-week period, a number of samples were collected from five areas that had been studied earlier. Animals and sediment samples were collected using a modified box core sampler. Sediments were screened for macrofauna and meiofauna, and box core samples were subsampled for sediment grain-size analysis. A Ponar grab was used for collection of benthic organisms for heavy metal analysis. This one intensive sampling effort was designed to provide data relating to three task areas:

- Task I - Benthic Community Investigations: describe community structure, abundance, and biomass at control and disposal areas.
- Task II - Stability of Deposited Material: describe and compare the sediment at control and disposal areas.
- Task III - Sediment Contaminant Investigations: determine mercury and cadmium concentrations in benthic species, sediment, and interstitial water at control and disposal areas.

Preliminary results (6) from the August 1979 samples are described in the following paragraphs.

Task I - Oligochaetes or freshwater worms were the dominant macrofaunal organism at both disposal and control areas; however, most individual species exhibited wide variations both within and among the five study areas. Nematodes were the dominant meiofaunal animal. The meiofauna in general showed more variability than the macrofauna. Organism abundance and diversity (number of species) were greatest in fine-grained sediments. Since the control areas' sediments were fine grained, abundance and diversity were generally greater in the control areas in comparison to the disposal areas. More snails were found at the disposal sites; more clams were found at the control sites.

Task II - Sediments at the disposal sites seemed to have changed since the DMRP study. They contained more sand and gravel with two areas showing random occurrence of up to 94 percent sand and gravel. Sediments in the control areas were similar in grain size to previous data. Sediment winnowing and drift were most likely responsible for the observed differences. The percentage of sand in each sample seemed to reflect the proportion of deposited dredged material.

Task III - No significant difference in the concentrations of mercury or cadmium in sediments from the control or disposal areas was found. There was no evidence that oligochaetes or clams found at the disposal sites had accumulated these metals to levels above control site organisms.

Elliott Bay Site

Work at the Elliott Bay disposal site began in March 1979 with a reconnaissance cruise to 30 stations at and near the previously studied DMRP site. Reconnaissance data were used to select 20 stations where samples were taken using a Van Veen grab, a gravity corer, or a specially constructed water sampler. These 20 stations were sampled three

times during 1979 and 1980. Data were sought for the following task areas:

- Task I - Effects on Benthic Invertebrates: (1) determine benthic colonization at the disposal area and compare with adjacent areas and (2) estimate changes in diversity, species richness, and biomass at disposal and adjacent areas, and the value of the disposal area habitat in comparison to unimpacted areas.
- Task II - Stability of Deposited Material: (1) estimate changes in the size and shape of the dredged material deposit and (2) investigate bottom current patterns and relate to bed load transport mechanisms.
- Task III - Mobilization of Polychlorinated Biphenyls: measure uptake of PCBs by benthic animals and relate to PCB levels in sediment, interstitial water, and near bottom water.

A final report on this study is not available at this time; however, the following paragraphs summarize the data that have been evaluated (7).

Task I - Data from the May 1979 cruise showed that species of animals found at the disposal site 9 months after disposal were still present and that the number of species had increased. The disposal site seemed to support a unique assemblage of animals. Certain species were much more abundant at the disposal site than in adjacent areas.

Task II - There was little change in the location or height of the disposal mound since 1976. Bottom currents at the disposal area were not strong and were calculated to be capable of moving only the finer sediment particles.

Task III - Sediment samples from the center of the disposal site were found to contain elevated levels of PCBs in comparison to adjacent areas. Total PCB residues varied both horizontally and vertically. There was evidence that some dredged material is slowly shifting from west to east. It is not yet clear whether PCBs are spreading or whether sediments carrying PCBs are moving. Levels of PCBs in interstitial and bottom waters were measurable; however, these water samples contained some fine sediment particles that probably account for the PCBs. Animals at the various stations generally reflect the PCB levels found in the sediments at those stations. For example, animals at one station contained an average of 3.9 ppm PCBs while sediment at the station contained 2.5 ppm. Animals at another station (outside the original disposal area) showed 0.4 ppm PCBs while the sediment contained 0.6 ppm.

HABITAT DEVELOPMENT SITES

DMRP Studies

Six wetland and three upland habitat development sites were established to demonstrate the feasibility of creating productive habitat on dredged material deposits (Figure 1). Wetland sites were located at Miller Sands (Columbia River, Oregon), Salt Pond 3 (South San Francisco Bay, California), Bolivar Peninsula (Galveston Bay, Texas), Apalachicola

Bay (Florida), Buttermilk Sound (Georgia), and Windmill Point (James River, Virginia). Upland sites were located at Miller Sands, Bolivar Peninsula, and Nott Island (Connecticut River, Connecticut). Questions regarding the ecological contribution and longevity of the sites raised after their construction were addressed.

DOTS Studies

In 1978, three reference areas were selected in the vicinity of each field site. Reference areas were chosen on the basis of their habitat quality, similarity to the type of habitat that had been the object of habitat development (e.g., salt marsh for salt marsh, broad-leaved emergent marsh for broad-leaved emergent marsh), and logistical proximity to the field site. The same parameters were to be monitored on both the reference areas and on the habitat development sites. Results from the reference areas would establish the range of natural variability to which data from the experimental sites could be compared.

Objectives for the monitoring program are:

a. Document, analyze, and compare plant communities and physical and chemical characteristics of the soils at the experimental wetland sites and reference areas.
b. Document, analyze, and compare sediment characteristics and selected aquatic biota at the experimental wetland sites and reference areas.
c. Document and compare the overall condition and appearance of both wetland and upland field sites over time with that of the reference areas.

Two levels of monitoring effort were developed. The first level included an annual general reconnaissance of all sites. General reconnaissance was intended to address the third objective (c) and to provide qualitative information on changes that might necessitate closer scrutiny (e.g., extensive erosion or large-scale plant mortality). The second level of monitoring was intensive sampling and was planned to provide quantitative data from selected major sites: Windmill Point, Buttermilk Sound, Bolivar Peninsula, Salt Pond 3, and Miller Sands. Intensive sampling was done at least once at each major site and included plant and soil sampling at all wetland sites and benthos and sediment sampling at Windmill Point, Bolivar Peninsula, and Miller Sands.

Plant and soil sampling was done randomly along elevation baselines. Sites were selected by elevation (in intertidal areas) or plant type (based on growth form). Transects and 0.5-m^2 quadrats were located randomly within elevational strata. The following parameters were determined from the plants occurring in each quadrat: species diversity, stem density (by species), height (mean height of 10 randomly selected stems), flowering phenology (number of flowering stems), aboveground biomass, and total root biomass.

Aboveground biomass was based on laboratory dry weight by species of all living aboveground parts. Total root biomass was determined at five 5-cm intervals from 0 to 25 cm and was based on laboratory dry weight of roots from a 25-cm cylindrical core, 10 cm in diameter, taken

from within the clipped 0.5-m^2 quadrat and wet-sieved through a 1-mm sieve.

Soil samples were taken at each plant sampling quadrat to a depth of 25 cm and, like the root samples, were divided into 5-cm increments. Soils were analyzed for various physical and chemical parameters depending on the site but usually included particle-size analysis, volatile solids, percent moisture, bulk density, pH, total Kjeldahl nitrogen, total phosphorus, and total organic carbon.

At Miller Sands, Bolivar Peninsula, and Windmill Point, samples were taken for analysis of macrobenthic invertebrates. At the latter two sites, the sampling was done as a three-part caging study in an effort to determine the rate of predation as well as to document and quantify the benthic population. For each benthic invertebrate sample collected, a corresponding sediment sample was taken and analyzed for grain size and volative solids.

In an effort to thoroughly document the status of the sites through time, aerial photographs were made from all the sites and reference areas during the growing season of 1979 or 1980. Low-level stereo, black and white, and color infrared photographs were taken.

Data analyses are still under way and will be synthesized into a report scheduled for completion in March 1982. Based on preliminary data analysis and qualitative observations, some general comments can be made at the present time regarding the status of each of the field sites.

Windmill Point

Windmill Point is an 8-ha island of freshwater intertidal marsh habitat developed using fine-textured sediments dredged from the James River navigation channel in the winter of 1974-75. The island was created by construction of a relatively inexpensive sand dike on the soft river bottom foundation. Hydraulically dredged fine-grained sediments were placed in the diked interior of the island within the intertidal zone; this area was rapidly colonized by native plant species. The marsh construction affected a displacement of the original shallow riverine aquatic habitat and produced a habitat of equal or greater value to the fish community (8). The dredged material marsh also provided cover for a large variety of birds (including waterfowl, passerines, shore and wading birds, and birds of prey) that found cover and/or food on the site's vegetated and unvegetated substrates.

The most recent observations (June 1980) indicated that the intertidal interior of the island continued to support a lush growth of broad-leaved emergent plants. They were dominated by pickerelweed (*Pontederia cordata*) and a sparse population of narrow-leaved emergents such as southern wild rice (*Zizaneopsis mileacea*). The same species occurred on the reference areas, but there the dominant vegetation was another broad-leaved emergent, arrow arum (*Peltandra virginica*). The reasons for this difference have not been definitely determined yet. The difference may be associated with the newness of the disposal site and its relatively early successional stage. Living biomass at the Windmill Point experiment site appeared to be similar to that found at the reference areas.

With regard to fish and wildlife, the disposal site appeared to provide excellent habitat. A massive population of fish, mostly carp (*Cyprinus carpio*), was observed to use the site for spawning during April 1979. Gulls and terns were observed using the sand dikes for resting habitat during the summers of 1979 and 1980. In addition, snags washed onto the dikes provided a feeding and resting place frequently used by four bald eagles (*Haliaeetus leucocephalus*) during 1979 and 1980.

Bolivar Peninsula

The Bolivar Peninsula habitat development site is located 16 km east of Galveston, Texas, and includes both marsh and upland habitat development experiments. The experimental site consists of 7.3 ha of hydraulically placed sandy dredged material. In January 1976, the site was graded and fenced, and a sandbag dike was constructed to protect the lower intertidal zone from the erosive forces of waves resulting from the long fetch of north winds sweeping across Galveston Bay.

Experimental plantings were established on both the intertidal and upland areas of the site in 1976 and 1977. Plantings at the intertidal zone demonstrated that both smooth cordgrass (*Spartina alterniflora*) and saltmeadow cordgrass (*S. patens*) could be successfully established on the dredged material. In the upland area, some of the experimental plant species that were successful included coastal bermuda grass (*Cynodon dactylon* Var. *alecia*), bitter panic grass (*Panicum amarum*), live oak (*Quercus virginiana*), winged sumac (*Rhus copallina*), and wax myrtle (*Myrica cerifera*). However, plant invasion was noted as a problem in plots planted with trees and shrubs (9).

The marsh development site at Bolivar Peninsula developed rapidly since its construction and first planting in 1976. Observations during October 1980 indicated that smooth cordgrass has spread throughout and thoroughly dominates most of the marsh site. There was little evidence of the checkerboard appearance the site initially displayed due to the agronomic test plot design that was used in the original experiment. Swards of saltmeadow cordgrass remained and there has been general invasion by both annual glasswort (*Salicornia bigelovii*) and perennial glasswort (*S. virginica*). The site has been heavily colonized by invertebrates such as the fiddler crab (*Uca pugnax*) and has received considerable use by small fish such as killifish (*Fundulus* sp.) during high tide periods. Based on general field observations, wildlife use by birds appeared equal that of the reference areas.

Preliminary data analysis indicated that plant growth and production based on stem height and aboveground biomass equaled or exceeded that on the reference areas; however, root biomass was less. Although plantings on the upland area continued to subsist, general invasion by other plants, particularly saltmeadow cordgrass, seashore dropseed (*Sporobolus virginicus*), and American bulrush (*Scirpus americanus*), had occurred.

Buttermilk Sound

The Buttermilk Sound marsh development site is a 2-ha intertidal marsh created by 1975-76 plantings in the intertidal zone on a deposit of sandy, infertile, hydraulically placed dredged material. Success of the plantings was related to the period of tidal inundation and type of propagule; sprigs were more successful than seeds, and smooth cordgrass was the most successful species planted (10).

The most recent field observations in 1980 indicated that smooth cordgrass thoroughly covered the site and surrounding areas. Swards of big cordgrass (S. cynosuroides) and saltmeadow cordgrass remained at middle and lower elevations where there had been planted originally. Saltmeadow cordgrass had invaded and dominated higher elevations where it had not been planted. Water hemp (Acnida cannabina), an invader, grew throughout the site. The Buttermilk Sound site appeared to differ from the reference areas by possessing greater species diversity at lower elevations. This is probably due to plant species introduced at the lower elevations in zones lower than those in which they normally occur. Aboveground growth appeared more lush, possibly due to nutrient availability giving plants more vigor. General observations indicated that wildlife use on the experimental site was similar to that on the reference areas.

Miller Sands

Miller Sands, a long-term disposal area, is a horseshoe-shaped island in the freshwater intertidal region of the Columbia River, Oregon. Sandy dredged material was last placed hydraulically in the intertidal region in 1975. The site was graded and plantings were established in 1976 and 1977. Plantings of tufted hairgrass (Deschampsia cespitosa) and slough sedge (Carex obnupta) were generally successful, especially at middle and higher elevations in the intertidal zone. Upland plantings of European beachgrass (Ammophila arenaria) were established on a sandspit surrounding the marsh in 1977 and were generally successful. An upland meadow on sandy dredged material dominated by a natural stand of scouring rush (Equisetum hyemale) was plowed, fertilized, and planted with a mixture of grasses and legumes. The plantings were generally successful and produced more aboveground biomass in 1977 than did unplanted areas. However, it was noted that the soils retained little moisture and were very infertile. This indicates that high productivity probably would not be sustained without continued maintenance (11).

Since its planting in 1976, the Miller Sands wetland site has continued to progress but at a slower rate than that for the other wetland habitat development sites. This may be due to slower growth rates of the species planted (i.e., tufted hairgrass and slough sedge), but is more likely associated with the cooler climate of the Oregon area. Nonetheless, the original plants that were successful in the upper one half of the intertidal zone at this site have persisted and continued to spread slowly into adjacent unvegetated areas. In addition, the site has experienced a considerable invasion by other plant species common in

surrounding marshes. Based on general observations, wildlife use appeared to be slightly less than that observed in the more densely vegetated reference marshes, but there appeared to be somewhat greater use of the experimental area by fish at high tides than was observed in the reference areas.

The upland sandspit plantings of European beachgrass continued to thrive based on observations in both 1979 and 1980. As anticipated, the upland site at Miller Sands no longer supported the lush pasturelike growth that occurred shortly after planting and fertilizing. The extreme droughtiness and infertility of the soil apparently require greater levels of management for enhanced growth. Although remnants of all the grasses and legumes planted still occur throughout the upland experimental site, the area appears to be reverting to a plant community similar to the one dominated by scouring rush that existed there formerly. Only tall fescue (Festuca elatior) appeared to have established a permanent, although low, level of production and spread throughout the site. Additional periodic management would be necessary to enhance the productivity of such a site.

Salt Pond 3

The Salt Pond 3 marsh development site was established on a portion of a 40.4-ha saltwater evaporation pond that was partially filled by hydraulic placement of clayey dredged material in 1974. Plantings of Pacific cordgrass (S. foliosa) and pickleweed (Salicornia spp.) were established during 1976 and 1977. Pacific cordgrass planted by sprigging was successful in the lower two thirds of the intertidal zone. Planting of the upper one third of the intertidal zone was not necessary as it was noted that this area was rapidly invaded and dominated by pickleweed (12).

Observations in 1979 indicated that the plantings at Salt Pond 3 maintained themselves and spread slowly into adjacent unvegetated areas. Production, based on biomass, did not appear to equal that on the reference sites. This measure was complicated, however, by the inability to differentiate biomass that resulted from growth during the current year and biomass that resulted from collecting the woody portions of the perennial pickleweed (Salicornia pacifica) that dominated the reference marshes. Also, the difference between disposal and reference sites may be due to the relatively early state of succession of the experimental site, but data analysis is not yet complete. Based on general observations, Salt Pond 3 received relatively heavy use by wildlife, particularly by shorebirds.

Nott Island

Dredged material consisting of sand from the main channel of the lower Connecticut River and silt from a nearby recreational channel was placed on an upland disposal site on Nott Island, Connecticut, in 1975-76. The sediments were mixed, limed, and planted with legumes and grasses in the summer of 1976. The sediments made a rather harsh environment for some domestic plant species; soil salinity was high and

acidity was low. Grasses established themselves and grew better than did legumes. Wildlife response to vegetation establishment was evident primarily through feeding activity (13).

Observations in 1980 confirmed the trends originally observed. Legumes showed only a sparse presence, while grasses were very successful, characterized by tall fescue, which dominated the site. Orchard grass (Dactylis glomerata) and timothy (Phleum pretense) were abundant subdominants. Where considerable amounts of silt were mixed with sand, the pasture mix had achieved a lush growth. Where there was a poor mix and the substrate was primarily sand, the growth was very poor and slow. Nonetheless, the site is quite stable with little or no change in rate or amount of growth and in species composition for the last three years (last observed in June 1980). This degree of success is very encouraging when one considers that the site received no management after its initial liming and planting. The site provides a useful habitat type interspersed among a number of other cover types and general observations indicate heavy wildlife use of the area.

Apalachicola Bay

The Apalachicola marsh project was developed on hydraulically pumped fine- and coarse-grained material placed in a saline intertidal environment in early 1976. Smooth cordgrass was planted on the fine-grained material and saltmeadow cordgrass was planted on the coarse-grained material between December 1976 and September 1977. Both species were successful; in addition, invaders, particularly saltgrass (Distichlis spicata), grew well in the coarse substrate at higher elevations (14).

Although this saltmarsh development site has been observed only by general reconnaissance, it is obvious that it has been extremely successful. The saltmarsh cordgrass planted on the fine-grained substrate has closed totally, and there is no evidence of the original planting pattern. The growth aboveground is lush and appears to be somewhat more vigorous than that of natural stands of smooth cordgrass at the reference area. This may be the result of the youthful age of the stand and the availability of abundant nutrients associated with the sediments. The saltmeadow cordgrass on the coarse-grained sediment has spread more slowly, but it has developed a dense sward. Saltgrass continues to be dense in that zone.

ENGINEERING VERIFICATION STUDIES

Research under the DMRP resulted in guidelines for designing, operating, and managing dredged material containment areas to meet required standards for effluent suspended solids as well as to provide adequate storage volume (15). Guidelines were also provided for dewatering fine-grained dredged material within containment areas (16). Field studies are being performed to verify or refine these design and dewatering methodologies. Some field studies have been completed and preliminary results are presented in subsequent paragraphs. Because of the nature of data required to verify certain methodologies, field

activities will be required to continue for several years to provide sufficient verification data.

The objective of the field studies is to verify the DMRP engineering methodologies, to the degree possible, for the range of dredging conditions experienced throughout the Corps. To achieve this objective, the field sites investigated must be representative of Corps dredging. A significant amount of effort has been devoted to identifying suitable sites for the studies, and this effort will continue to ensure that the verification work provides meaningful results.

Sites have been selected and field verification studies have either been completed or initiated at six active disposal sites; four additional sites have been identified for studies during FY 81. The sites include dredging activities in both freshwater and saltwater environments.

Containment Area Sizing to Retain Suspended Solids

Freshwater design procedures contained in Reference 15 were evaluated at a 37-acre rectangular (length-to-width ratio of about 3) disposal site. Field measurements included determination of influent and effluent suspended solids in addition to a dye-tracer test to determine detention time and dispersion characteristics. The influent suspended solids content averaged about 109 g/ℓ, and the effluent content was about 8 g/ℓ. The material was not contaminated so the effluent suspended solids content was within the allowable limits for the site. The theoretical detention time for the site was 107 hours; the mean detention time determined from the dye-tracer test was 48 hours, about 45 percent of the theoretical detention time. The tracer test also indicated that there was a very large amount of dispersion.

Settling tests were performed to estimate the suspended solids removal capability of the basin. Based on these tests, the mean detention time computed for the required sedimentation of solids (<8 g/ℓ) was 45 hours. This time is required for removal of suspended solids to achieve a level of 8 g/ℓ in the upper 1 ft of the water column. Research on weir design to meet effluent quality (17) that was the basis for the guidelines in Reference 15 indicated that during flow over the 100-ft weir at this site, the depth of the withdrawal zone would be expected to be limited to the upper 1 ft of the sedimentation basin water column. The 45 hours computed for detention time required for sedimentation based on the laboratory tests compares favorably with the 48 hours measured as the mean detention time of the basin. When the laboratory value was increased by the recommended factor of 2.25 (15) to account for scale-up and basin inefficiencies, about 102 hours was computed as the design detention time based on the laboratory data. This value compares favorably with the theoretical detention time of 107 hours computed for the basin.

A containment area being used for disposal of dredged material from a saltwater environment was sampled to determine dredged material concentration in the basin during a 23-day disposal operation. These measurements were needed to provide data on increase in dredged material concentration during the disposal activity to verify the concentrations determined in the laboratory in 8-in.-diameter column sedimentation tests

using sediments from the project. (The 8-in.-diameter column tests are specified in Reference 15 for both freshwater and saltwater sediments.)

During the 23-day disposal period, samples were taken at various depths at a number of points within the basin. These data indicated that the water above the water/solids interface in the basin was low in suspended solids at all times during the disposal activity and that below the interface, the solids concentration increased with depth and time. At the end of the 23-day period, the average concentration was about 300 g/ℓ. From the 8-in.-diameter column sedimentation tests, an average concentration of about 340 g/ℓ was estimated for dredged material in the basin at the end of a 23-day disposal activity. Statistical analyses performed on the data indicate that there were no significant differences between the field and laboratory determinations of solids concentrations for this project. These preliminary results indicate that realistic, conservative concentration design parameters can be obtained from the long-term column laboratory test using an 8-in.-diameter column.

Preliminary results from the field verification tests indicate that the settling tests and design procedures recommended for freshwater sediments provide design estimates that agree closely with actual field values. However, additional cases will be evaluated before these procedures are considered to be substantiated by field experience.

A significant amount of work is required on estimating the hydraulic efficiency of dredged material sedimentation basins before exact design correction factors can be established to account for scale-up and flow-through problems. Based on the work accomplished to date, a correction factor of 2.25 appears reasonable. This factor is higher than those recommended in the environmental engineering literature, which are generally based on experience with wastewater treatment facilities. However, the conditions experienced at a dredged material containment area are more complex than those of wastewater treatment facilities. There have not been enough tracer tests performed to provide a strong relationship between the correction factors and the length-to-width ratios of the containment areas.

Suspended Solids Removal by Chemical Treatment

Gravity sedimentation processes will remove most suspended solids from dredged material discharged into a containment area, with the level in the effluent depending on the settling properties of the sediment and the characteristics of the containment area. However, in some instances, agencies in the United States have established suspended solids effluent criteria that are too low to be met by gravity sedimentation alone. In such cases, it is necessary to provide additional treatment for further reduction of suspended solids. Laboratory and limited field studies during the DMRP indicated that chemical coagulation of fine-grained dredged material greatly influenced the efficiency of the sedimentation process.

There are a number of unique problems associated with using polymer flocculents to increase removal of suspended solids from containment

area effluents. Although the use of polymers to treat waters and wastewaters is a well-established practice, such polymer treatment principles are not easily extended to dredged material disposal operations. The high flow rates and remote locations of most containment areas can render the use of conventional treatment processes economically infeasible. Also, liquid products are preferred over powder to eliminate the problems in preparing large amounts of polymer solution at the remote dredging sites.

The basic features of chemical treatment include polymer injection, mixing, and settling. Elaborate structures developed for wastewater treatment are impractical for dredged material containment areas. It is important to adapt existing conditions at containment areas into usable treatment facilities to minimize the costs of chemical treatment. Through the field demonstrations, treatment systems that require only minimal modifications for application to active containment areas have been developed and successfully demonstrated. The energy generated at most containment area weir structures is adequate to provide the necessary mixing of polymer with effluent to promote good flocculation of solids.

Two full-scale demonstrations of chemical treatment of containment area effluents have been completed, and a third is planned for early 1981. Although all three demonstrations involve freshwater environments, laboratory tests performed on sediments from a proposed saltwater site indicate that good results could be achieved with treatment. High-molecular-weight cationic polymer flocculents were used effectively in reducing effluent solids concentrations in the first two demonstrations. A low-molecular-weight cationic polymer has been selected for the third demonstration because it will be easier to handle and mix.

In the first field demonstration, a 120-ft fixed-crest weir controlled the flow from a 48-acre containment area into a secondary settling and storage basin. The chemical was jetted into the effluent as it plunged over the weir crest. Mixing was accomplished by a system of eight parallel rows of baffle boards mounted on the concrete chute. The effectiveness of the baffled mixing system was evaluated by injecting dye at the weir overflow point and observing the dispersion through the baffled system. This test proved that good mixing of the polymer could be expected. Polymer was then injected for a period of 28 hours. This time period was adequate to evaluate the effects of treatment during the normal variability of the dredging operation. The mean dosage rate during the demonstration was about 15 mg/ℓ. The results of this demonstration were quite promising. Effluent suspended solids were reduced from an average of 3.75 g/ℓ to an average suspended solids level of 0.475 g/ℓ. It is likely that even better suspended solids removal would have been obtained if the polymer treatment had been applied for a longer time period.

The second demonstration was performed at a containment area with a drop inlet weir structure between the containment basin and a settling basin. The dredging environment and settling properties of the dredged material were similar to those of the first demonstration. A major objective of this demonstration was to explore the feasibility of reducing the dosage rate to reduce the cost of polymer treatment.

The polymer dosage rates were reduced from 15 mg/ℓ to 6 and 4 mg/ℓ based on the results of laboratory jar tests designed to determine the most effective polymer and the optimal dosage rates. The flow rate of about 25 cfs was similar to that of the first demonstration. The head differential of about 15 ft in the drop inlet weir structure provided sufficient energy for mixing and flocculation. No modifications to the existing containment area were necessary for this demonstration. Polymer was applied at a rate of 6 mg/ℓ for 24 hours, and an average reduction in effluent suspended solids of 92 percent was measured. A polymer dosage rate of 4 mg/ℓ used for 10 hours resulted in an average reduction in suspended solids concentration of 82 percent. The results of reducing the polymer dosage rate were positive, and a dosage rate of about 4 mg/ℓ will be used in the planned third field demonstration.

The results of the field demonstrations of chemical treatment indicated that polymer injection into the weir overflow from containment areas is an effective means for reducing effluent suspended solids. Costs for treatment were minimized by designing treatment systems that used existing containment facilities, to the extent possible, without major construction modifications. However, secondary settling basins are required for sedimentation of the treated dredged material.

Preliminary DMRP studies of the concept of injecting polymers into the dredge pipeline instead of treating containment area effluents indicated that pipeline injection may be impractical from an economic standpoint because injection into the dredge pipeline would require significantly higher polymer dosage rates. However, studies will be continued for a conclusive evaluation of pipeline polymer injection treatment concept.

Dewatering Methodologies

The major technical unknown in application of dewatering methodologies is the exact rate at which fine-grained dredged material dewatering, densification, surface subsidence, and crust formation will occur. Field studies have been initiated in containment areas at four locations to provide data on these rates. These data will be evaluated and used to verify and refine dredged material dewatering methodologies (15, 16). These studies will provide a basis for evaluating the volume gained in containment areas from management of surface water to promote maximum drying and crust formation. In addition to verification and refinement of dewatering methodologies, the fieldwork will provide data on costs and benefits associated with containment area management activities undertaken for in-place dewatering of the dredged material. Because of the nature of the information required, several years of data collection will be necessary before meaningful results can be reported. The sites have been sampled to determine initial conditions of the dredged material and have been instrumented to provide data to evaluate dewatering and densification with time. A significant amount of field data will be obtained during FY 81, and preliminary results will be reported as soon as the data are analyzed.

SUMMARY

Results of the various activities under way were summarized within each section of this paper. Technical reports will be prepared during 1981 on all of the efforts. Plans are under way to extend the efforts at least through 1982 to gain additional information on the long-term effects of open-water disposal, the behavior of habitats developed by disposal of dredged material, and the engineering characteristics of material placed in containment areas.

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WATER QUALITY IMPROVEMENT BY RETARDATION OF NUTRIENT RELEASE
-ESTIMATION AND ANALYSIS BY A SIMPLIFIED MODEL-

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SUMMARY

A simplified model of nutrient flow is applied to estimate the influence of nutrient release on water quality. Steady-state analysis shows that cutting off the release from sediment makes the organic concentration diminish greatly in the inner eutrophic bay of Osaka.

1. INTRODUCTION

In eutrophic bays, a great deal of organic material is produced through photosynthesis. In summer, the organic load assimilated in the sea often exceeds the inflowing load from the land. The organic concentrations or phytoplankton concentrations are the primary concern in water quality management.

Phytoplankton assimilates the inorganic nutrient with sunlight to synthesize organic bodies. Produced organics easily settle onto the bottom sediment. Restored organics in the sediment consume the dissolved oxygen (DO) in bottom water. An aerobic condition in bottom water not only destroys the ecological equilibrium of benthic biota but also makes the

nutrient release increase in rate. The illustration of the nutrient and organics flow is shown in Fig.-1.

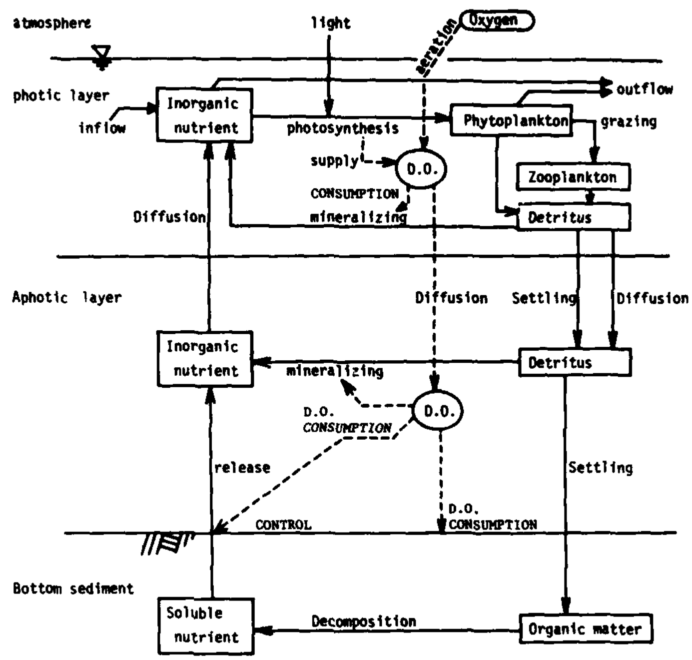

Fig.-1 Illustration of nutrient flow

The nutrient cyclic process is composed of many elemental factors such as production, decomposition, settling, release, and diffusion. The organic standing concentration is determined by the kinetics of various processes taking place in the aquatic environment. In order to predict the change of water quality by some new impact, we must understand both the rate equations of each elemental factor and the structure of the whole kinetics. A numerical modeling and simulation can be the powerful means to the understanding of the behavior of such complicated systems. If the relations between each concentration of various nutrient forms and each rate of various processes are known with sufficient accuracy, we can predict the changes of the whole system.

In this paper, we will try to understand the role of the nutrient release from the sediment to the water quality. For this purpose, a simplified model of nutrient flow is treated herein. Fig.-2 shows the model with arrows (processes) and frames (nutrient form). This model is built under the assumption that organic production is controlled by only one nutrient[1]. Seawater is vertically separated into two layers - upper photic layer and lower aphotic

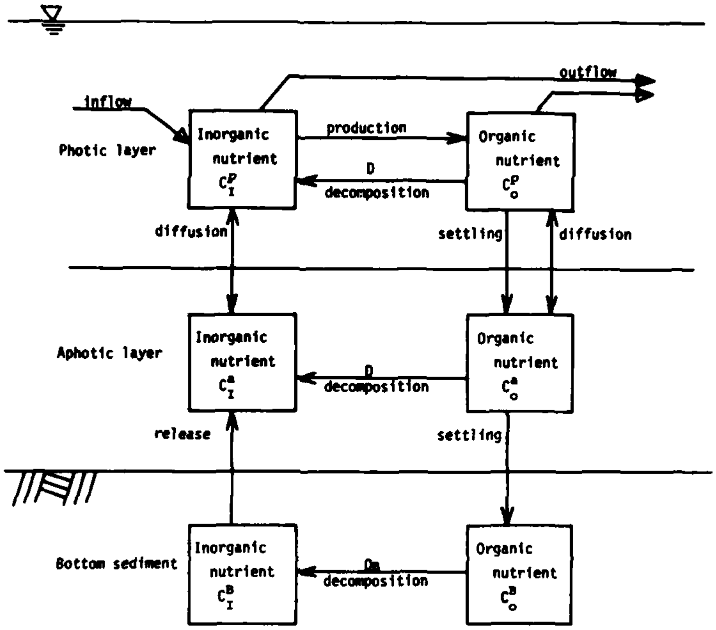

Fig.-2 Simplified nutrient flow system
(1 segment, 2 layer + sediment system)

layer. Each layer is assumed to be homogeneous. This model contains 6 nutrient forms C_I^p, C_O^p, C_I^a, C_O^a, C_I^B, C_O^B. C_I means the inorganic concentration and C_O the organic concentration. C^p, C^a, and C^B represent the concentration in photic layer, aphotic layer, and bottom sediment, respectively. Though the similarity to the actual phenomena lessens, it is easier for us to understand the behavior of the system if the model is more simplified[2].

2. STEADY-STATE ANALYSIS

2-1 System Analysis of the Simplified Model

The simplified nutrient flow model (shown in Fig.-2) is described by the following 6 equations:

$$V^p \frac{dC_I^p}{dt} = K(C_I^a - C_I^p) + DC_O^p V^p - \mu \frac{C_I^p}{K_M + C_I^p} C_O^p V^p + \beta({}_{in}C_I - C_I^p) V^p \qquad (1)$$

$$V^p \frac{dC_o^p}{dt} = K(C_o^a - C_o^p) - DC_o^p V^p + \mu \frac{C_I^p}{K_M + C_I^p} C_o^p V^p - \frac{S}{h_p} C_o^p V^p - \beta C_o^p V^p \tag{2}$$

$$V^a \frac{dC_I^a}{dt} = K(C_I^p - C_I^a) + DC_o^a V^a + \theta R C_I^B W \tag{3}$$

$$V^a \frac{dC_o^a}{dt} = K(C_o^p - C_o^a) + \frac{S}{h_p} C_o^p V^p - \frac{S}{h_a} C_o^a V^a - DC_o^a V^a \tag{4}$$

$$W \frac{dC_I^B}{dt} = -RC_I^B W + D^B C_o^B W \tag{5}$$

$$W \frac{dC_o^B}{dt} = -D^B C_o^B W + \psi \frac{S}{h_a} C_o^a V^a \tag{6}$$

where V^p, V^a are the water volume of the photic layer and that of the aphotic layer, respectively,

W is the bottom sediment weight within the effective depth,

K is the coefficient representing the strength of the vertical diffusion between two layers,

D is the decomposition rate from organic nutrient form to inorganic form,

μ is the maximum growth rate depending on the temperature and the light intensity,

K_M is the half-saturation concentration for C_I,

β is the exchange rate of the water (reverse of the mean hydraulic retention time),

${}_{in}C_I$ is the mean inflowing concentration of nutrient,

S is the settling velocity,

h_p, h_a are the mean depth of the photic layer and the aphotic layer, respectively,

R is the release rate from sediment,

D^B is the decomposition rate from particulate organics to soluble inorganics in the sediment.

In eqs.(1)-(6), each process is expressed by linear function except the production process which is to be a Monod type reaction. The inflowing organic load (${}_{in}C_o$) is relatively small compared to ${}_{in}C_I$.

In summer, the release rate R can be assumed to be constant under the

anaerobic condition. We can also assume that C_I^B and C_o^B are constant because the settling flux ($S/h \cdot C_o^a \cdot V^a$) and the release flux ($R\ C_I^B W$) are too small to alter the standing mass $C_I^B W$ and $C_o^B W$. Then, assuming steady-state for Eqs. (1)-(6), we can get the following algebraic equations

$$0 = \frac{K}{V^p}(C_I^a - C_I^p) + DC_o^p - \mu \frac{C_I^p}{K_M + C_I^p} C_o^p + \beta({}_{in}C_I - C_I^p) \tag{7}$$

$$0 = \frac{K}{V^p}(C_o^a - C_o^p) - DC_o^p + \mu \frac{C_I^p}{K_M + C_I^p} C_o^p - \frac{S}{h_p} C_o^p - \beta C_o^p \tag{8}$$

$$0 = \frac{K}{V^a}(C_I^p - C_I^a) + DC_o^a + \frac{r}{h_a} \tag{9}$$

$$0 = \frac{K}{V^a}(C_o^p - C_o^a) + \frac{S}{h_a}(C_o^p - C_o^a) - DC_o^a \tag{10}$$

where r is the release rate constant of the nutrient (mg/m^2/d).
In steady-state solutions ($\dot{C}_I^p$, $\dot{C}_o^p$) for (C_I^p, C_o^p) are:

i) for $\mu > F$ and $\left(\frac{r}{\beta h_a} + {}_{in}C_I\right) > \frac{K_M \cdot F}{\mu - F}$

$$\dot{C}_I^p = \frac{K_M \cdot F}{\mu - F} \tag{11}$$

where

$$F = D + \beta + \frac{S}{h_a} + \frac{h_a}{h_p} \cdot \frac{\frac{K}{V^a} D}{\frac{K}{V^a} + \frac{S}{h_a} + D}$$

$$\dot{C}_o^p = \frac{1}{\left(\frac{S}{h_a} + \beta + \frac{-D(S/h_p)}{\frac{K}{V^a} + \frac{S}{h_a} + D}\right)} \left\{\frac{r}{h_p} + \beta({}_{in}C_I - C_I^p)\right\} \tag{12}$$

ii) for $\mu \leq F$ or $\left(\frac{r}{\beta h_p} + {}_{in}C_I\right) \leq \frac{K_M F}{\mu - F}$

$$\dot{C}_I^p = \frac{r}{\beta h_p} + {}_{in}C_I \tag{13}$$

$$\dot{C}_o^p = 0 \tag{14}$$

The solutions $\dot{C}_I^p$ and $\dot{C}_o^p$ are rather complicated. If we represent the whole system by simpler model, we can derive simpler solutions with a smaller number of rate

constants.[3),4)] Some of the simpler models and their solutions are shown in Appendix-B. In any case, the following characteristics of the solutions can be easily pointed out:

1. $\dot{C}_I^p$ is independent of its inflow concentration $({}_{in}C_I)$. According to Eq.(11), $\dot{C}_I^p$ increases with the total decrease rate $(D+\beta+S/h_p)$ of $\dot{C}_o^p$. And $\dot{C}_I^p$ decreases with the growth rate (μ). If μ is less than F and input concentration $(\frac{r}{\beta h_p}+{}_{in}C_I)$ is very small at the same time, then washout of C_I^p becomes dominant. Under this condition, $\dot{C}_I^p$ equals to $(\frac{r}{\beta h}+{}_{in}C_I)$ and $\dot{C}_o^p$ is zero.

2. $\dot{C}_o^p$ depends on those parameters as r, ${}_{in}C_I$, β, S. Eq.(12) demonstrates that $\dot{C}_o^p$ is proportional to the inorganic input load $(\frac{r}{h}+\beta\,{}_{in}C_I)$ minus washout load (βC_I^p).

$$C_o^p \propto \text{(release load)+(inflowing load)-(outflowing load)} \qquad (15)$$

The release load (r/h) plays a more important role to $\dot{C}_o^p$ as the release load is increased compared to inflow nutrient load $(\beta\,{}_{in}C_I)$.

3. In a closed system where inflow and outflow will not occur (β=0) and total standing mass of the nutrient in the system is conserved $(d(\Sigma C_i V_i)/dt=0)$, it is the decomposition rate, growth rate, settling rate, and hydraulic parameters that determine the partitioning of nutrients among various organic and inorganic form fractions except $\dot{C}_I^p$ (see Appendix-B #1M, #3, and #4). In other words, the equilibrium state is a function of the initial state in closed systems, while in open systems the steady-state is a function of its input and output.

2-2 Estimation of Parameters

In order to examine the contributions of various processes to $\dot{C}_o^p$ numerically, estimation of the rate constants and other parameters is required. Let us consider the inner Osaka Bay in the summer condition as an example. Fig.-3 shows the inner eutrophic part of the Osaka Bay. Table-1 shows the hydraulic profile of the bay. Provisional values of the rate constants and parameters are listed in Table-2. These values are picked up from the summer observation data or other researchers' data[5)]. In this area, phosphate is a limiting nutrient which governs the organic production (see Appendix-A). In summer, the internal release load from the sediment (12.1 ton/d) is calculated to be an amount

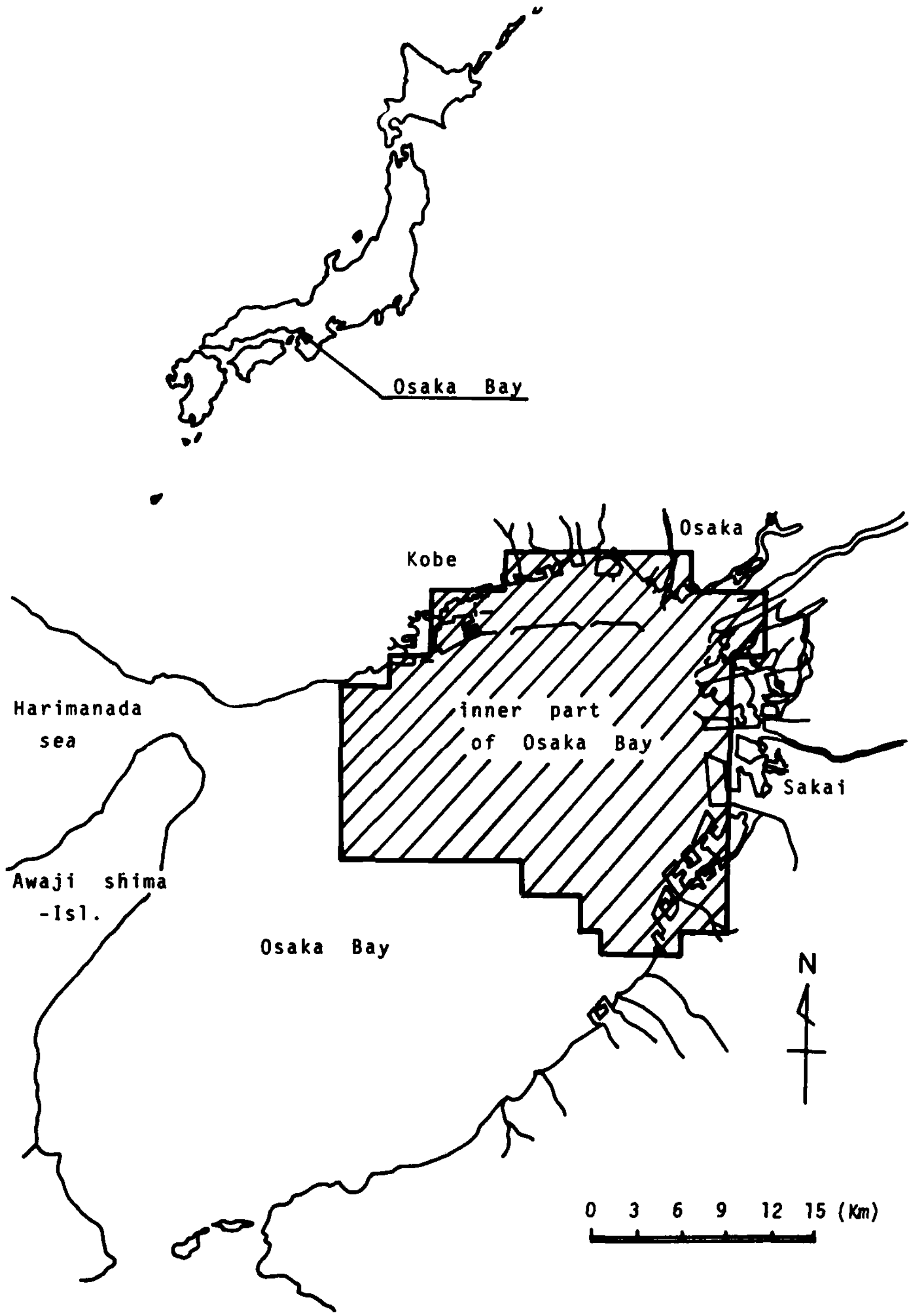

Fig.-3 Osaka Bay

similar to the external inflowing load from the urban area (14.4 ton/d). Necessary conditions for steady-state solutions are now ready.

Table-1 Dimensions of the inner Osaka Bay

volume	photic layer	V^p	$4.04 \times 10^9\ m^3$
	aphotic layer	V^a	$2.56 \times 10^9\ m^3$
surface area		A	$4.04 \times 10^8\ m^2$
mean depth	photic layer	h^p	10.0 m
	aphotic layer	h^a	6.3 m
tidal range for M2 component			0.31 m
	exchanging volume	Q	$0.25 \times 10^9\ m^3/d$
mean discharge in August			
	fresh water inflow	q	$0.036 \times 10^9\ m^3/d$
	fresh water quality		0.4 mg - P/l
	in flow nutrient load		14.4×10^9 mg/d
	release rate	r	30 mg - $P/m^2/d$ (observation data in 1975)
	release nutrient load		12.1×10^9 mg/d
mean water quality in August			
	photic layer		
	PO4-P	C_I^p	0.04 mg/l
	Salinity		26.48 ‰
	aphotic layer		
	PO4-P	C_I^a	0.15 mg/l
	Salinity		31.56 ‰
vertical diffusion coefficieint in summer		kz	$2.16\ m^2/d\ (0.25 cm^2/sec)$

Table-2 Rate constants and parameters

process	parameter	symbol	value (unit)
production process			
	maximum growth rate in summer	μ	0.4 (1/d)
	half-saturation coefficients for P	Km	0.03 (mg/l)
decomposition process			
	decomposition rate	D	0.01 (mg/l)
settling process			
	settling velocity	S	0.4 (m/d)
	settling rate in photic layer	S/hp	0.04 (1/d)
	settling rate in aphotic layer	S/ha	0.063 (1/d)
release process			
	release rate	r	30 $(mg/m^2/d)$
	concentration increase by release	r/hp	3×10^{-3}(mg/l/d)
diffusion process			
	vertical diffusion coefficient	kz	2.16 (m^2/d)
	vertical diffusion rate	K/V^a	0.0418 (1/d)
			$K = kz \cdot A/(\frac{ha+hp}{2})$
water exchange process			
	mean water exchange rate in photic layer	β	0.047 (1/d)
			$\beta = (q_s + Q\frac{hp}{ha+hp})/Vp$
mean quality of inflow		in C_I	0.076 (mg/l)
			in C_I = inflow flux / Vp / β

2-3 Steady-State Analysis

The nutrient flow in the steady-state condition is described in Fig.-4.

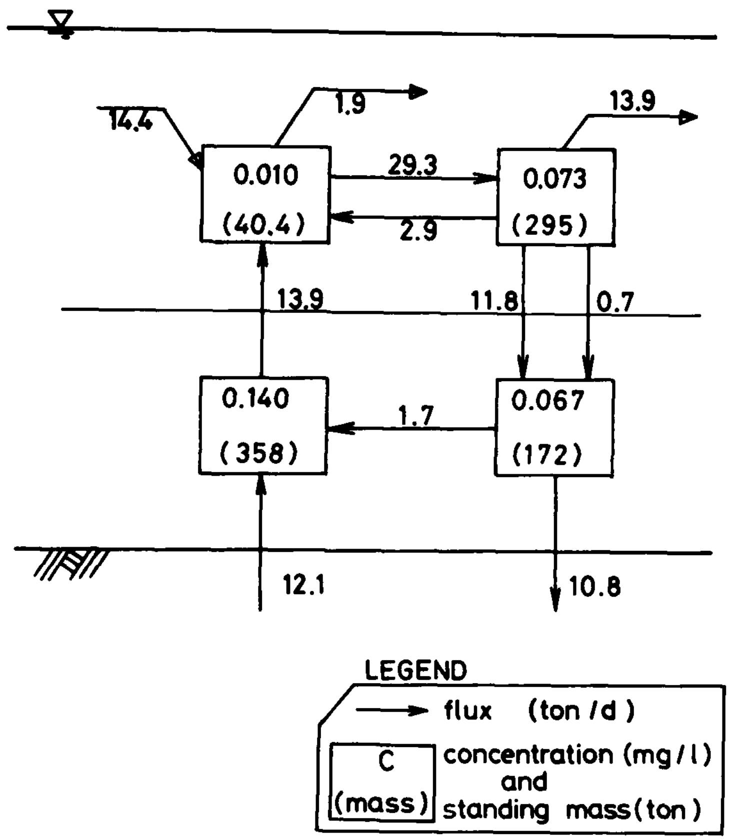

Fig.-4 Nutrient budget in equilibrium state

In the figure, the processes are shown with arrows. Each value of the flux (ton/d) is indicated beside the arrow. Nutrient concentration (mg/l) and standing mass (ton) of each form are shown in the frame.

Diffusion flux from $\dot{c}_I^a$ to $\dot{c}_I^p$ (13.9 ton/d) and inflow load to $\dot{c}_I^p$ (14.4 ton/d) are estimated to be of a similar order. Most of the sum of the fluxes which flow into $\dot{c}_I^p$ assimilate to organics $\dot{c}_o^p$ (29.3 ton/d). Washout flux from $\dot{c}_I^p$ is very little. About half of the assimilated organics flow out to the off-shore sea (13.9 ton/d). Another half settle down into the aphotic layer (11.8 ton/d). Diffusion flux and decomposition flux from $\dot{c}_o^p$ are calculated to be small. Organics in the aphotic layer $\dot{c}_o^a$, which is settled down from photic layer $\dot{c}_o^p$, also easily settle onto the bottom sediment. Among various

processes in which organics decrease, the settling process is demonstrated to be dominant in the shallow water of inner bay. Accumulated nutrient in the sediment gradually changes its form to soluble nutrient and returns to the aphotic layer.

Looking at the nutrient budget in the sediment, the release flux (12.1 ton/d) slightly exceeds the settling flux (10.8 ton/d). This fact may be temporarily found only in summer season. Usually the majority of nutrients tends to be stored in the bottom sediment.

Due to the low rate of settling and diffusion processes, standing mass in water is accumulated in the forms of C_o^p and C_I^p. Standing mass in the sediment is estimated to be about 12000 tons, if the effective depth is 0.1m from the sediment surface. This value is very much greater than the release flux or the settling flux.

Eqs. (11)-(14) still require the estimation of the various rate constants. Then, let's analyze the sensitivity of these constants to $\dot{C}_o^p$. $\dot{C}_o^p$ is described by S/h_p, β, $D\dfrac{S/h_p}{K/V^a+S/h_p+D}$, r/h_p, $\beta_{in}C_I$, and $\beta\cdot\dot{C}_I$. Estimating the orders of the values of the first three constants, S/h_p and β is about tenfold greater than $D\dfrac{S/h_p}{K/V^a+S/h_p+D}$. Among the last three constants, release load (r/h_p) and inflow load ($\beta_{in}C_I$) are similar and washout flux (βC_I) is much less in the area. Thus, S, r, ${}_{in}C_I$, and β are principal factors of C_o^p. Sensitivity of each parameter near the steady-state condition is shown in Table-3. In this

Table-3 Sensitivity of parameters to $\dot{C}_o^p$

parameter	symbol	parameter value	parameter value increasing in 10%	$C_o^{p'}$	$C_o^{p'}/C_o^p$
release rate	r	30 mg/m^2/d	33 mg/m^2/d	0.0767 mg/l	1.049
mean inflow concentration	in CI	0.076 mg/l	0.0836 mg/l	0.0773 mg/l	1.059
exchanging rate	β	0.047 1/d	0.0517 1/d	0.0724 mg/l	0.990
settling velocity	S	0.4 m/d	0.44 m/d	0.0696 mg/l	0.953
degradation rate	D	0.01 1/d	0.011 1/d	0.0733 mg/l	1.003
vertical diffusion coefficient	k	2.16 m^2/d	2.376 m^2/d	0.0730 mg/l	0.999

$\dot{C}_o^p$ = 0.0730 mg/l

The values of $C_o^{p'}/C_o^p$ are increasing / decreasing non-linearly except for r, in CI.

table, each $\dot{C}_o^p$ is the calculation result when each parameter is increased by

10%, respectively, and each $\dot{C}_O^{p'}/\dot{C}_O^p$ is the ratio between $\dot{C}_O^{p'}$ and $\dot{C}_O^p$. This ratio represents the sensitivity. Among the parameters, r and ${}_{in}C_I$ especially prove high sensitivity to $\dot{C}_O^p$ and contribute very much to $\dot{C}_O^p$. We may point out at the same time that sensitivities of β and S are non-linear.

When the release is cut off to zero, $\dot{C}_O^p$ will be diminished to 0.037 mg/l, which corresponds to nearly the half value of $\dot{C}_O^p$ in Fig.-4.

2-4 Unsteady-State Analysis

For steady-state analysis, we have assumed that the nutrient flow holds almost equilibrium conditions during summer. For the analysis of seasonal changes and stability of the system, however, we need to treat the system as nonsteady-state. Unsteady-state analysis is much more complicated than steady-state analysis, and sometimes less feasible. We can obtain the analytical solutions of time-dependent basic equations only for the simplest system (see Appendix-B#1).

In this paper, unsteady-state simulation was used to examine the feasibility and the stability of the steady-state analysis. Using the Runge-Kuttaa method, concentrations of each nutrient form (C_I^p, C_O^p, C_I^a, C_O^a) are calculated directly from Eqs.(1)-(4). Rate constants and parameters are used as exactly the same values as listed in Tables-1 and -2. The time interval for calculations is 0.25 day. Initial concentrations of C_I^p, C_O^p, C_I^a, and C_O^a are 0.04, 0.02, 0.15, and 0.02 (mg/l), respectively. Release load is assumed to be a constant 12.1 ton/d just as in the steady-state analysis. We have calculated the following 5 cases:

i). reference case using the values in Table-1 and Table-2,

ii). reduced inflow case reducing the inflow load by half (to 7.2 ton/d),

iii). cut-off release case cutting the release load off to zero,

iv). reduced inflow and cut-off release case,

v). increased exchange rate case increasing the exchange rate by twice (keeping same inflow load).

The changes of C_I^p and C_O^p versus time are shown in Fig.-5.a-e.

C_I^p is more rapidly approaching the steady-state solution than C_O^p. Both C_I^p and C_O^p are near the equilibrium values in 30 to 40 days. Under the condition shown in Tables-1 and -2, steady-state analysis is a useful and

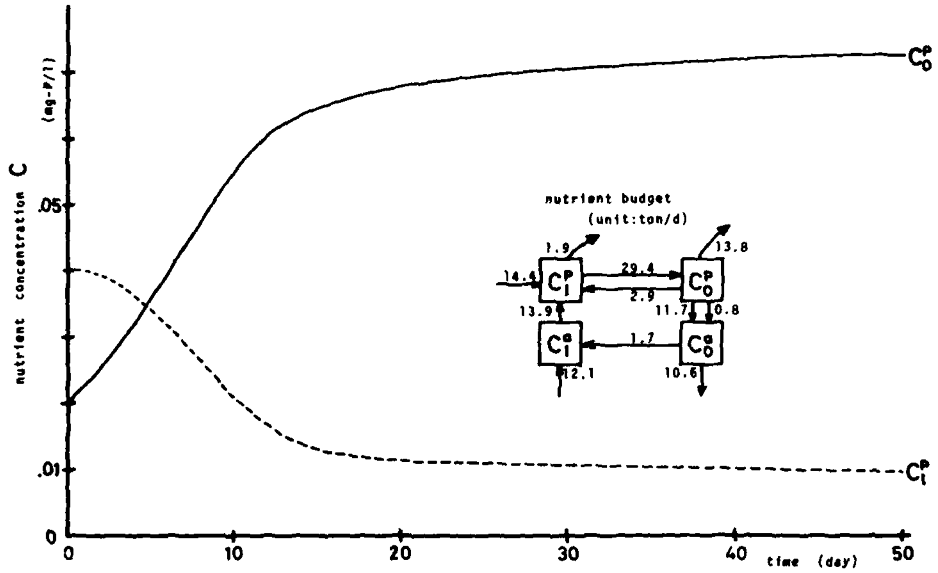

Fig.-5.a Change of concentrations of C_I^p and C_O^p with time (reference case)

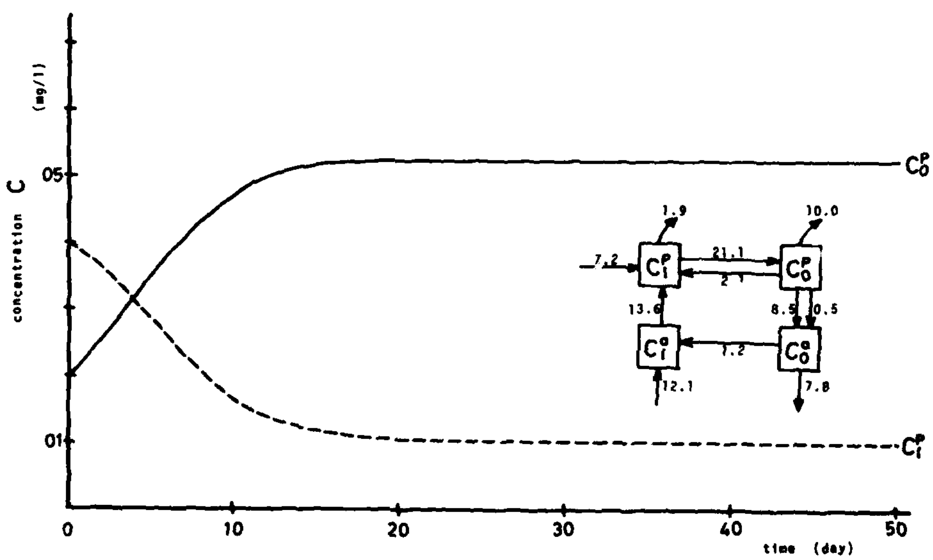

Fig.-5.b Change of concentrations of C_I^p and C_O^p with time (inflow load reduction by half)

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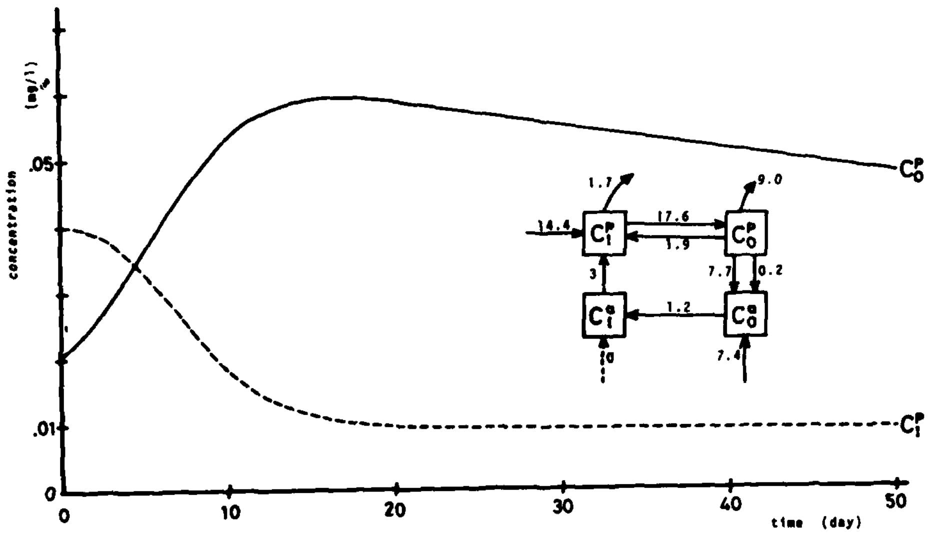

Fig. 5.c Change of concentrations of C_I^p and C_O^p with time (release load cut-off)

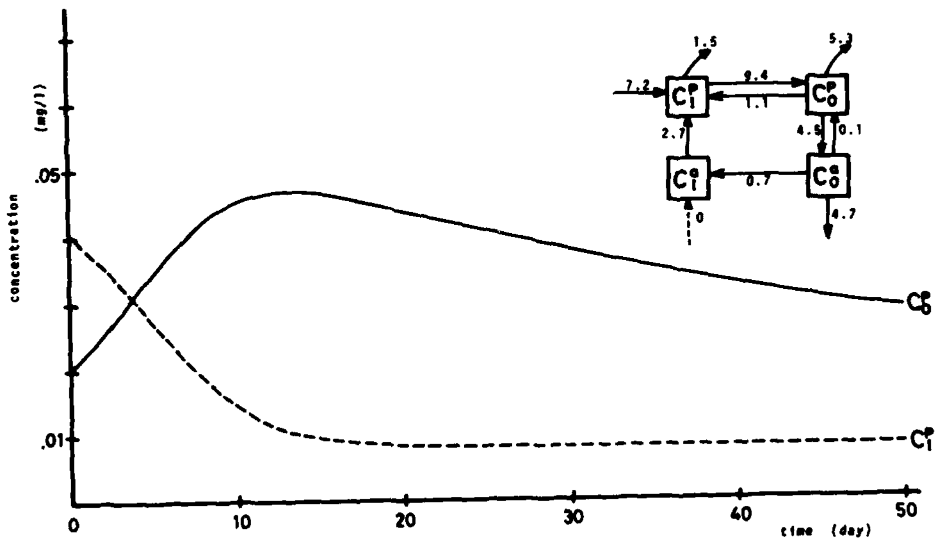

Fig.-5·d Change of concentrations of C_I^p and C_O^p with time
(inflow load reduction and release cut-off)

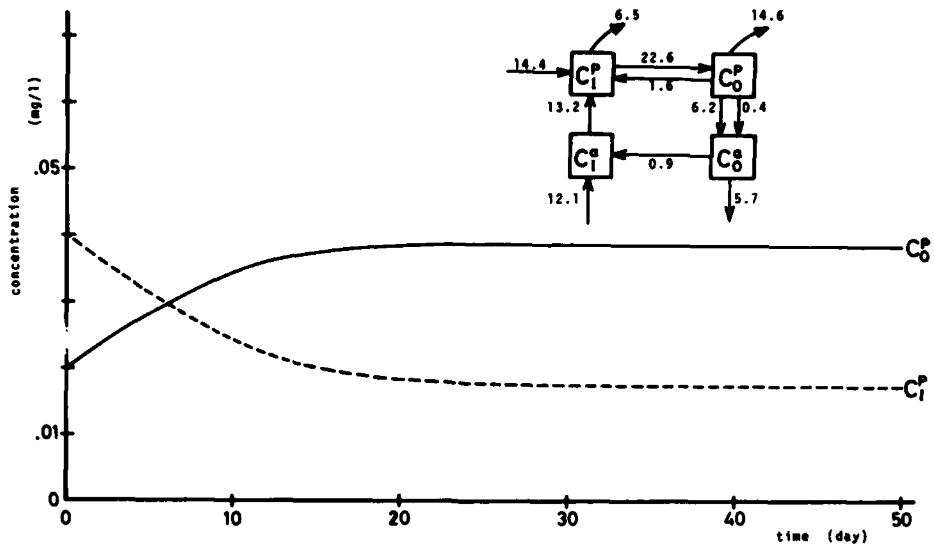

Fig.-5·e Change of concentrations of C_I^p and C_O^p with time (twofold increase in exchange rate)

successful means to approximately estimate the complex flow dynamics. Steady-state solutions are taken to represent mean values for summer.

Comparing each simulation value of C_O^p after 50 days with that for the reference case, it is reduced by 30% for cut-off release case, 30% for reduced inflow case, and 60% for reduced inflow and cut-off release case. It takes more time to approach the equilibrium $\dot{C}_O^p$ in the cases of cut-off release than in the case of reduced inflow. In cut-off release cases, the peak of C_O^p appears after two weeks.

We can point out the intense effect of the exchanging rate on C_O^p. In Fig.-5·e, an obvious decrease is observed in C_O^p. It is also important to estimate hydraulic parameters accurately and carefully.

3. FEASIBLE METHOD FOR RETARDATION OF NUTRIENT RELEASE

In the previous section, we discussed the important role of nutrient release to organic concentration. Next of interest is how to diminish the release rate. To do this, the laboratory experiment is conducted on the phosphate release from the sediment.

It is known that release rate of phosphate increases with temperature and T-P concentration in the sediment[6]. Under anaerobic conditions, the rate also increases a great deal. Thus, improving DO in the lower layer and lessening soluble P by the treatment of sediment surface may be an applicable technique. To investigate the influence of DO and sediment sealing on release rate, two experiments were performed.

i) The natural bottom sediment was sampled from the inner Osaka Bay by using the cylindrical pipes (100cm in height and 30cm in diameter) with negligible disturbance. The depth of the sediment was 30cm. Above the sediment, natural seawater was added. Immediately after the sampling, these pipes with sediment and water were carried in the laboratory. DO concentration was controlled by weak bubbling of air or N_2 gas. Water in the pipe was sampled every day for two weeks and the phosphate concentration was measured. From the concentration data and water depth, the release rate of each DO case was calculated. The results are shown in Fig.-6.

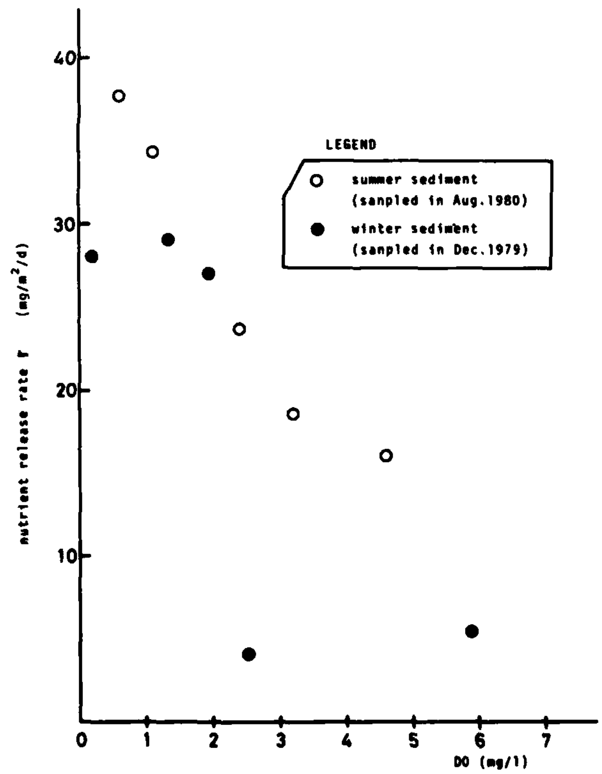

Fig.-6 Change of release rate by DO (laboratory experiment at 28°C)

The release rate evidently decreases with DO. In aerobic conditions, the rate is estimated as being as little as one tenth of that in anaerobic conditions.

Improving DO in bottom water is very effective not only in recovering the benthic biota but in lessening the phosphate release rate.

ii) A sealing experiment was conducted using 2-ℓ glass cylinders. Mixed sediment was placed on the bottom of each cylinder up to 10cm in height. Above the sediment, fine mud taken from the land or sand taken from the sea-shore was placed from 2 to 5cm in thickness.

Seawater was added and the change of phosphate concentration was measured for 3 to 4 days. The results are shown in Fig.-7. These results indicate that

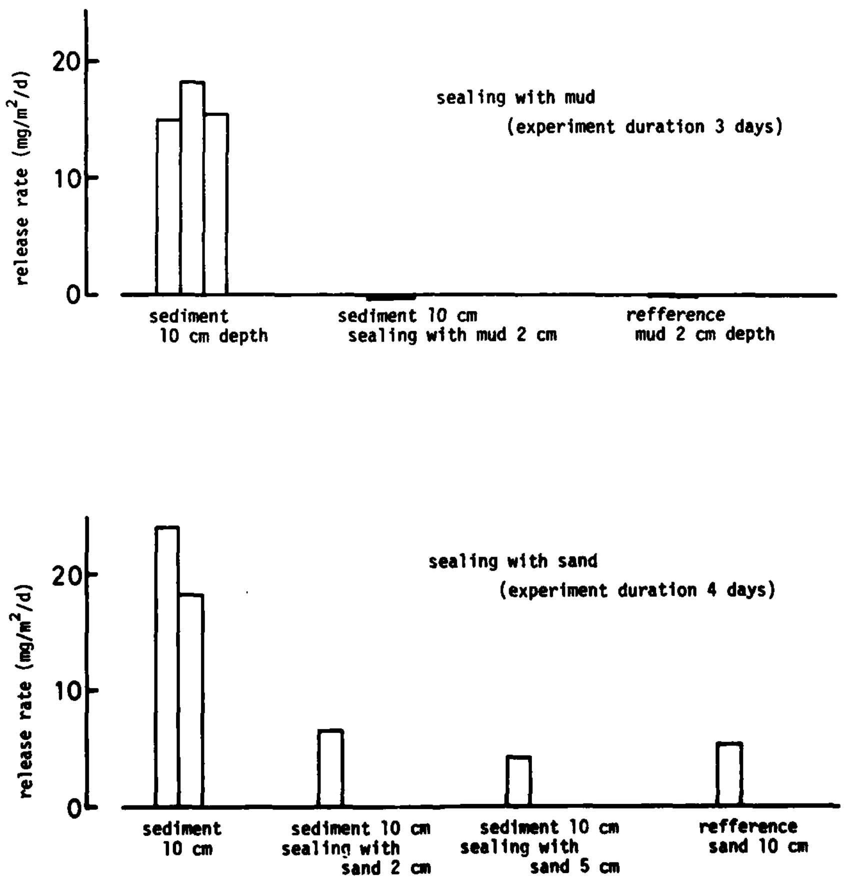

Fig.-7 Sealing experiment

sealing is also an effective means to reduce release rates.

The phosphate diffusion process and the soluble phosphate supply process in sediment may be important to analyze the mechanism of release. These processes will be investigated in the future.

4. CONCLUSIONS

The effect of nutrient release on water quality is numerically examined by using a simplified model.

The system analysis resulting from the model shows the following characteristics:

(1) in steady-state analysis

a) inorganic concentration in the photic layer mainly depends upon such parameters as growth rate, exchange rate, settling velocity, and half-saturation concentration.

b) organic concentration in the photic layer mainly depends upon internal and external nutrient load, settling velocity, and exchange rate.

c) according to the estimation of each parameter which governs nutrient flux of each process (using the example of the inner Osaka Bay), the settling process is comparatively important relative to the degradation process in the water.

d) the effect of the retardation of release depends upon the ratio between the nutrient release load and the inflowing load. As the internal release load is greater than external load, the improvement effect on water quality becomes more distinguished.

(2) in unsteady-state analysis

a) If the values of each parameter and rate constant are considered pertinent, the system may approach the equilibrium state within a month.

b) the retardation of release is more effective than the decrease of inflowing load for the improvement of water quality.

c) hydraulic parameters such as current, diffusion coefficient, etc., are also important factors to the numerical estimation of the improvement effect.

Laboratory experiments on nutrient release from sediment show that DO improvement and sediment sealing are effective and feasible countermeasures to lessen release rate.

The Third Port Construction Bureau helped us to obtain the experimental material and the related data. We thank those concerned.

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Appendix A

Following the Marine Algal Assay Procedure-Bottle test[7] the algal growth potential (AGP) was measured in Osaka Bay in August 1977[8]. After the sterilization of the sampled water, Dunaliella tertiolecta (green algae) was cultivated for two weeks under the condition of 19°C ±2°C and 8000 lx (light 16h-dark 8h). Maximum standing crop in the cultivation is called AGP, which represents the algal growth potential of sampled water. AGP and observed data on phytoplankton in the field are listed in Table-A.1.

Table-A.1 Relation between AGP and plankton in surface water

index / station	Osaka Bay in summer			
	A.G.P.	chl-a	P.O.C.	total plankton cell number
	cells/ml	µg/l	mg/l	cells/ml
St. 1		53.5	3.8	6604
St. 2		29.0	5.1	3611
St. 3	58800	7.7	0.8	2011
St. 4		10.9	3.2	7610
St. 5	39100	7.1	0.8	2366
St. 6	70700	33.5	1.6	2286
St. 7	50700	8.7	4.4	2005
St. 8		5.6	2.5	3361
St. 9	122500	111.7	3.6	13016
St.10	55900	29.0	1.5	3340
St.11	72400	8.4	0.6	3021
St.12	59500	4.9	1.3	1227
St.13	48400	6.3	0.8	2862
St.14	74900	24.0	2.1	3573
St.15	98900	33.3	2.4	7911
correlation coefficient with A.G.P.	r(n=11)	0.953	0.448	0.900

Chaetoceros spp. and Skeletonema costatum were the dominant species in the field. AGP shows good correlation with the field plankton data. AGP represents the available nutrient concentration to the growth of the field phytoplankton. AGP also correlates with nutrient concentration especially phosphate in summer as shown in Table-A.2. Nutrient concentration was measured by chemical

Table-A.2 Correlations between AGP and nutrient concentration

	T - N	I - N	T - P	I - P	sample number
summer	0.586	0.279	0.845	0.798	n=45
winter	0.896	0.930	0.975	0.979	n=12

procedures. It may be said that phosphate concentration decides AGP and field algal growth in Osaka Bay in summer.

For further reference, the distribution of AGP in Osaka Bay in summer is shown in Fig.-A.1. The high value of AGP is obtained in the bottom water of the inner bay due to the phosphate release from the sediment.

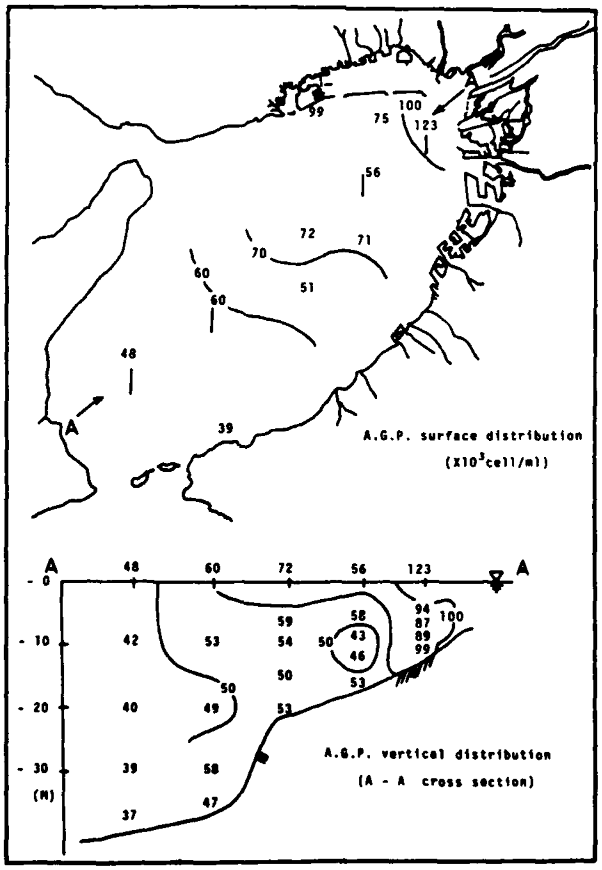
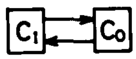


Fig.-A.1 AGP distribution in summer

Appendix B

Where different structures of the nutrient flow are possible, interactions within the system influence the form of the steady-state. Any mathematical modelling of the eutrophication must be based upon some knowledge of the system structure. It is of interest to compare the expressions for the steady states of hypothetical simplified systems of different complexities to determine the differences in their functional dependencies. Some cases with basic equations and nutrient flows in the steady-state condition are shown in Fig.-B.1. In any case, the

#1 流入流出のない、沈降・溶出のない一層システム
(one-layer two state variables system)



基礎式 (basic equation)

$$\begin{cases} \dfrac{d\, C_I\, V}{d\, t} = D\, C_o\, V - \mu \dfrac{C_I}{K_M + C_I} C_o \cdot V \\ \dfrac{d\, C_o\, V}{d\, t} = -D\, C_o\, V + \mu \dfrac{C_I}{K_M + C_I} C_o\, V \\ \dfrac{d(C_I + C_o)\, V}{d\, t} = 0 \quad \text{(or)} \quad C_I + C_o = \overset{*}{C} \end{cases}$$

定常解 (steady state solution)

$$\begin{cases} \dot{C}_I = \begin{cases} \dfrac{K_M \cdot D}{\mu - D} & (\mu > D) \\ \overset{*}{C} & (\mu \leq D) \end{cases} \\ \dot{C}_o = \begin{cases} \overset{*}{C} - \dot{C}_I & (\mu > D) \\ 0 & (\mu \leq D) \end{cases} \end{cases}$$

非定常解 (non-steady state solution for $\mu > D$)

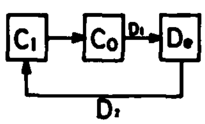
$$\frac{(C_I - \dot{C}_I)^{(\dot{C}_I + K_m)}}{(C - \overset{*}{C})^{(\overset{*}{C} + K_m)}} = A \cdot \exp\left[-(\mu - D)(\overset{*}{C} - \dot{C}_I) \cdot t\right]$$

ここで、(where) $A = \dfrac{(\check{C}_I - \dot{C}_I)^{(\dot{C}_I + K_m)}}{(\check{C}_I - \overset{*}{C})^{(\overset{*}{C} + K_m)}}$

, ただし $\check{C}_I = C_I$ at $t=0$

Fig.-B.1.a Characteristics of simplified systems (#1)

#1M 流入流出なし デトライタスを含むシステム
(one-layer three state variables system)



基礎式 (basic equation)

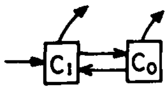
$$\begin{cases} \dfrac{d\, C_I\, V}{d\, t} = D_2 \cdot D_e \cdot V - \mu \dfrac{C_I}{K_M + C_I} C_o\, V \\ \dfrac{d\, C_o\, V}{d\, t} = \mu \dfrac{C_I}{K_M + C_I} C_o\, V - D_1\, C_o\, V \\ \dfrac{d\, D_e\, V}{d\, t} = D_1\, C_o\, V - D_2\, D_e\, V \\ \dfrac{d\,(C_I\, V + C_o\, V + D_e\, V)}{d\, t} = 0 \\ \qquad (C_I\, V + C_o\, V + D_e\, V = \overset{*}{C}\, V) \end{cases}$$

定常解 (steady state solution)

$$\begin{cases} \dot{C}_I = \dfrac{K_M\, D_1}{\mu - D_1} \\ \dot{C}_I = \dfrac{D_2}{D_1 + D_2} (\overset{*}{C} - \dot{C}_I) \\ \dot{D}_e = \dfrac{D_1}{D_1 + D_2} (\overset{*}{C} - \dot{C}_I) \end{cases}$$

Fig.-B.1.b Characteristics of simplified systems (#1M)

2 流入流出あり 沈降・溶出なし 一層システム
(one-later with inflow-outflow system)



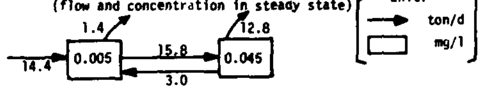
基礎式

$$\begin{cases} \dfrac{d\,C_I V}{d\,t} = D\,C_O V - \mu \dfrac{C_I}{K_M + C_I} C_O V + \beta V(\text{in } C_I - C_I) \\ \dfrac{d\,C_O V}{d\,t} = -D\,C_O V + \mu \dfrac{C_I}{K_M + C_I} C_O V - \beta V C_O \end{cases}$$

定常解

$$\begin{cases} \dot{C}_I = \begin{cases} \dfrac{K_M (D+\beta)}{\mu - (D+\beta)} & \mu > D + \beta \text{ and in } C_I > \dfrac{K_M (D+\beta)}{\mu - (D+\beta)} \\ \text{in } C_I & \mu \le D + \beta \text{ or in } C_I \le \dfrac{K_M (D+\beta)}{\mu - (D+\beta)} \end{cases} \\ \dot{C}_O = \text{in } C_I - \dot{C}_I \end{cases}$$

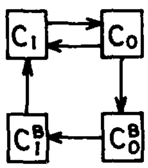
定常時の flux図
(flow and concentration in steady state)



$\mu = 0.4$ $K_M = 0.03$ $D = 0.01$
$V = 6.60 \times 10^9 m^3$ $\beta = 0.043 = \dfrac{(250 + 36)}{6.6 \times 10^9}$
$\text{in } C_I = 0.0507$

Fig.-B.2.c Characteristics of simplified systems (#2)

3 流入流出のない、沈降・溶出のある、水⇄底泥システム
(water - sediment interaction system)



基礎式

$$\begin{cases} \dfrac{d\,C_I V}{d\,t} = D\,C_O V - \mu \dfrac{C_I}{K_M + C_I} C_O V + R \cdot C^B_I \cdot W \\ \dfrac{d\,C_I V}{d\,t} = -D\,C_O V + \mu \dfrac{C_I}{K_M + C_I} C_O V - S/h\, C_O V \\ \dfrac{d\,C^B_I W}{d\,t} = D_B\, C^B_O W - R \cdot C^B_I \cdot W \\ \dfrac{d\,(C_I V + C_O V + C^B_I W + C^B_I W)}{d\,t} = 0 \\ \qquad \text{or } C_I V + C_O V + C^B_I W + C^B_O W = V \overset{*}{C} \end{cases}$$

定常解 (for $\mu > D + S/h$ and $\overset{*}{C} > \dfrac{K_M (D + S/h)}{\mu - (D + S/h)}$)

$$\begin{cases} \dot{C}_I = \dfrac{K\ (D + S/h)}{\mu - (D + S/h)} \\ \dot{C}_O = \dfrac{R\ D_B}{R\ D_B + S/h\ D_B + S/h\ R} (\overset{*}{C} - \dot{C}_I) \\ \dot{C}^B_I = \dfrac{S/h\ D_B}{R\ D_B + S/h\ D_B + S/h\ R} (\overset{*}{C} - \dot{C}_I) \cdot \dfrac{V}{W} \\ \dot{C}^B_O = \dfrac{S/h\ R}{R\ D_B + S/h\ D_B + S/h\ R} (\overset{*}{C} - \dot{C}_I) \cdot \dfrac{V}{W} \end{cases}$$

$V = 6.60 \times 10^{12}$ (litter)
$W = 4.04 \times 10^9 \times 60$ (Kg)

非定常解（擬似解）(non-steady state Pseudo-solution)

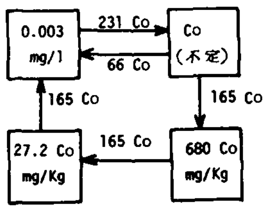
if we can assume $\mu \frac{C_I}{K_M + C_I} = \mu \frac{\dot{C}_I}{K_M + \dot{C}_I}$ around $(\dot{C}_I, \dot{C}_O)$,

then

$$C_O - \dot{C}_O = -(\dot{C}_O - \check{C}_O)\exp\left[\left(\mu \frac{\dot{C}_I}{K_M + \dot{C}_I} - D - S/h\right)\cdot t\right]$$

$$\check{C}_O = C_O \text{ at } t = 0$$

定常時の flux 図



$\frac{V}{W} = 272$

$R = 0.25$ 30 mg/m²/日

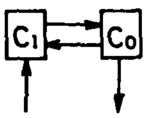
(C_I^B = 2 mg/Kg で 12.1 ton/日)

$S/h = 0.025$

$D_B = 0.01$

Fig.-B.2.d Characteristics of simplified systems (#3)

#3M 流入流出のない 沈降 溶出のある 一層システム
(one-layer with settling - release system)



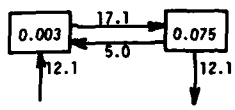
基礎式

$$\begin{cases} \dfrac{d\, C_I V}{d\, t} = D\, C_O V - \mu \dfrac{C_I}{K_M + C_I} C_O V + r/h \cdot V \\ \dfrac{d\, C_O V}{d\, t} = -D\, C_O V + \mu \dfrac{C_I}{K_M + C_I} C_O V - S/h\, C_O V \end{cases}$$

定常解 (μ $D + S/h$)

$$\begin{cases} \dot{C}_I = \dfrac{K_M(D + S/h)}{\mu - (D + S/h)} \\ \dot{C}_O = \dfrac{r}{S} \end{cases}$$

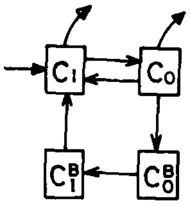
定常時の flux 図



$r = 30^{mg}/m^2/$日

Fig.-B.2.e Characteristics of simplified systems (#3M)

\# 4 流入流出のある、沈降 溶出のある、水⇄底泥システム
(water - sediment interaction with inflow-outflow system)



基礎式

$$
\begin{cases}
\dfrac{d\,C_I V}{d\,t} = D\,C_O V - \mu \dfrac{C_I}{K_M + C_I} C_O V + \beta V(in\,C_I - C_I) + R\,C_I^B W \\[2mm]
\dfrac{d\,C_I V}{d\,t} = -D\,C_O V + \mu \dfrac{C_I}{K_M + C_I} C_O V - \beta V C_O - S/h\,C_O V \\[2mm]
\dfrac{d\,C_I^B W}{d\,t} = -R\,C_I^B W + D_B C_O^B W \\[2mm]
\dfrac{d\,C_O^B W}{d\,t} = -D_B C_O^B W + S/h\,C_O V
\end{cases}
$$

定常解 (for $\mu > D + \beta + S/h$, and $in\,C_I > \dfrac{K_M (D + \beta + S/h)}{\mu - (D + \beta + S/h)}$)

$$
\begin{cases}
\dot{C}_I = \dfrac{K_M (D + \beta + S/h)}{\mu - (D + \beta + S/h)} \\[2mm]
\dot{C}_O = in\,C_I - \dot{C}_I \\[2mm]
\dot{C}_I^B = \dfrac{S/h \cdot V}{R\,W} (in\,C_I - \dot{C}_I) \\[2mm]
\dot{C}_O^B = \dfrac{S/h\ V}{D_B\,W} (in\,C_I - \dot{C}_I)
\end{cases}
$$

定常時の flux 図

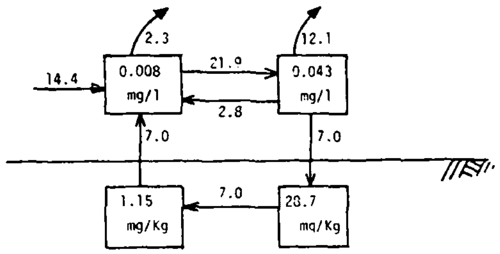
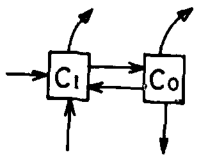


Fig.-B.2.f Characteristics of simplified systems (#4)

\# 4 M 流入流出のある 沈降 溶出のある 一層システム
(one-layer with settling - release,and inflow-outflow system)



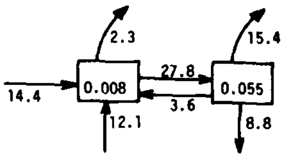
基礎式

$$
\begin{cases}
\dfrac{d\,C_I V}{d\,t} = D\,C_O V - \mu \dfrac{C_I}{K_M + C_I} C_O V + \beta V (in\,C_I - C_I) + r/h \cdot V \\[2mm]
\dfrac{d\,C_O V}{d\,t} = -D\,C_O V + \mu \dfrac{C_I}{K_M + C_I} C_O V - \beta\,C_O V - S/h\,C_O V
\end{cases}
$$

定常解 ($\mu > D + \beta + S/h$, &, $in\,C_I > \dfrac{K_M (D + \beta + S/h)}{\mu - (D + \beta + S/h)}$)

$$
\begin{cases}
\dot{C}_I = \dfrac{K_M (D + \beta + S/h)}{\mu - (D + \beta + S/h)} \\[2mm]
\dot{C}_O = \dfrac{1}{\beta + S/h} \left[\dfrac{r}{h} + \beta (in\,C_I - \dot{C}_I) \right]
\end{cases}
$$

定常時の flux 図



$h = 16.3$ m

$r = 30$ mg/m²/日 $\times \dfrac{6.6 \times 10^3}{16.3} = 12.1$

$\left.\begin{aligned} \beta &= 0.043 \\ in\,C_I &= 0.051 \end{aligned}\right) \times 6.6 \times 10^3 \quad 14.4$

$S = 0.4$

$\mu = 0.4$

$D = 0.01$

$K_M = 0.03$

Fig.-B.2.g Characteristics of simplified systems (#4M)

models in Fig.-B.2 are assumed to be reasonable simplifications so that interactions among the components can be made clear. Fig.-B.2 contains the following systems:

#1 : one-layer system with two state variables (C_I and C_O)
#1M : one-layer system with three state variables (C_I, C_O, and detritus D_e)
#2 : one layer with inflow-outflow open system
#3 : water-sediment interaction system
#3M : one layer with settling-release system
#4 : water-sediment interaction with inflow-outflow open system
#4M : one layer with settling-release and inflow-outflow open system.

#1, 1M, 3, and #3M are the closed systems without inflow-outflow.

DISSOLVED OXYGEN CONSUMPTION IN LAKE SEDIMENTS

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SUMMARY

Oxygen uptake by bottom sediments from Lake Yunoko and Lake Kasumigaura was measured with an electrolytic respirometer. Sediment oxygen demand (SOD) ranged from 2.5 to 29.0 mg O_2/g dry sediment. Sediments obtained from anaerobic bottoms showed higher values of SOD than those from aerobic bottoms.

The first-order kinetics was applied to analyze oxygen uptake curves (the amount of oxygen consumed by unit weight of sediments vs. time). From the difference of uptake rate coefficients, SOD was fractionated into three phases, i.e. rapid chemical oxidation (1st phase), and fast and slow biological oxidation (2nd and 3rd phase, respectively). The first phase continued only a few hours followed by the second phase that continued from 5 to 10 hours. The first phase constituted up to 70 % of the total SOD in the anaerobic sediments, whereas that was not observed in the aerobic and unpolluted sediments.

INTRODUCTION

One of the environmental concerns resulting from eutrophication is oxygen depletion of the water mass.[1] Along with the direct effects of oxygen depletion on the biological community in water, oxygen depletion has a significant effect on the nutrient budget in the water body, i.e. oxygen concentration around bottom sediments is known to be one of the most important factors to control phosphorus and/or nitrogen release from sediments into overlying water.[2)-5)] It also has a significant role in

nitrification and denitrification processes in water and sediments.[6)]

There have been many studies conducted on simulation models of lake ecosystems to predict future water quality in the lake and to assess the effect of man's activity on the lake system.[7)-11)] Although there are a few exceptional models that consider the change in oxygen concentration in lake water,[9),10)] models that incorporate the effects of oxygen concentration on nutrient budget are rare. In many lakes, however, nutrient release plays an important role in water quality;[11)] therefore, the dissolved oxygen balance in lakes should not be neglected in a cohesive model for a lake ecosystem.

Some studies, including simulative works, have focused on the oxygen balance in water bodies.[12)-15)] Two of the most important processes of oxygen sink are water column oxygen demand and sediment oxygen demand (SOD). Water column demand has been documented by using dark bottle techniques, although the results obtained are not satisfactory because evaluation of the effects of sedimentation, wall effects, and changes in microbial composition is difficult.[14)] The latter, SOD, has been reported with major emphasis from various circles. A variety of techniques have been employed to determine SOD both in laboratories and in the field.[16)] It is now generally accepted that SOD can be divided into biological and chemical components although the relative importance of biological vs. chemical SOD varies from sediment to sediment;[12),17)-22)] i.e. the contribution of the chemical oxidation to the total SOD ranges from 8 %[21)] up to 100 %.[22)] These fractionations were achieved by adding toxic chemicals such as phenol,[20)] potasium cyanide,[20)] m-cresol,[21)] antibiotics,[22)] etc., to inhibit bacterial respiration.

Some of the above-mentioned results have been derived from experiments that used sediment core.[12),17),20),23),24)] It is apparent, however, that kinetic information cannot be derived without an effort to analyze diffusion and reaction processes in the sediment layer of the core. Studies that used a homogeneous sediment-water mixture have derived kinetic constants on the rate of oxygen uptake,[18),19)] and the ratio of biological respiration and chemical oxidation to the total SOD. It has also been noticed that the rate of oxygen uptake depends on the dissolved oxygen concentration.[14),23),25)] The purpose of this study is to fractionate SOD and to determine kinetic constants under saturated dissolved oxygen

concentration by using a electrolysis-based manometric procedure. Both the aerobic and anaerobic (at the surface of the sediments) bottom sediments in eutrophic lakes were investigated and fractionations were conducted without chemical additions.

MATERIALS AND METHODS

Sediment samples were taken from Lake Kasumigaura and Lake Yunoko by using a coring device (Rigosha, Tokyo). The first lake is the second largest in Japan (167 km^2 surface area), but is a shallow (3.9 m average depth), eutrophic lake, located in southern Ibaraki prefecture (ca. 70 km northeast of Tokyo). Sediment cores were taken at a shallow station (2.5 m) with aerobic overlying water throughout the year. The second lake is a small (0.35 km^2 surface area), deep (7.5 m average depth), eutrophic lake, located at an elevation of 1748 m in Tochigi prefecture (ca. 120 km north of Tokyo). The central area of this lake annually becomes low in dissolved oxygen from the onset of stratification during early summer until the autumn overturn. Sediment cores taken at the lake center (12 m) in August had anaerobic overlying water, whereas those taken in October had aerobic water. The samples were tested for SOD as soon as possible after delivery to the laboratory.

About 20 cm of the sediment cores taken in plexiglas tubes (5 cm inner diameter × 30 cm), were divided into 2.5- or 5-cm-thick layers. Each cylindrical core was mixed completely with a glass rod to obtain an homogeneous sediment sample. SOD was evaluated for each sediment sample by using a electrolytic respirometer (Coulometer, Okura Electric, Tokyo). Five milliliters of wet sediment was injected, using a 20-mℓ plastic syringe, into the electrolysis cell (500 mℓ) where 300 mℓ of distilled water had been placed more than 6 hr earlier. The cell was placed in a constant temperature unit of the respirometer, and water temperature of 20 °C was secured during this period. The injection of the sediment sample showed little effect on the temperature of the sediment-water mixture; therefore, the movement of the manometer originating from the temperature difference between the electrolytic cell and the reference cell was avoided. The measurement of oxygen consumption was initiated

immediately after the injection of the sediment. Sediment-water mixture in the electrolytic cell was mixed continuously and steadily by a magnetic stirrer. The measurement was closed when the rate of increase in SOD became negligible (less than 5 % of SOD per day).

A 500-ml Erlenmeyer flask was used to determine immediate oxygen demand of the sediments. A 2.5-ml sediment sample was put into the flask. The flask was filled with aerated and temperature controlled (20 °C) distilled water and sealed with a glass cap. Oxygen concentration in the flask was analyzed using procedures described in Standard Methods.[26] During this incubation, the sediment-water mixture was stirred continuously. The same analysis was also conducted for the flask that was added with $CuSO_4$ (2.0 g/l) to differentiate biological respiration from chemical oxidation.[27]

All sediment samples were separately determined for dry weight, i.e. a portion of wet sediment of a known volume was weighed before and after drying in a oven at 105 °C for 2 to 3 days.

RESULTS AND DISCUSSION

Oxygen uptake by 1-ml sediment samples collected at Lake Kasumigaura in August is shown in Fig. 1A. The amount of oxygen consumed, sediment oxygen demand (SOD), per unit volume of sediment increased in samples taken from deeper layers. Rapid oxygen uptake was observed within the first 5 hours followed by slow uptake. SOD levelled off within 260 hours (not shown in Fig. 1). About 50 % of the final SOD was consumed during the rapid uptake period. Although the overlying water of this sediment was aerobic, the potential of oxygen uptake by surface sediments was large. Surface sediment, from 0 to 2.5 cm, consumed 1 mg oxygen per 1 ml sediment, thus the decrease of dissolved oxygen concentration in overlying water column of 2 m depth would be 5 mg O_2/l if 1 cm of surface sediment was suspended homogeneously into the overlying water column. Fig. 1B shows oxygen uptake per unit dry weight of the same sediments calculated from the data obtained in dry weight measurements. Contrary to the result on unit volume basis, this result showed smaller differences among the depths of sediments.

Oxygen uptake by anaerobic bottom sediments sampled at Lake Yunoko (lake center) in August 1978 is shown in Fig. 2. Larger values of SOD per unit volume (Fig. 2A) were observed in deeper sediments. The same tendency was noted in SOD per unit volume irrespective of sampling time (August and October), dissolved oxygen concentration in the overlying water, and station (Kasumigaura and Yunoko) within the range of measurements in this study. SOD ranged from 0.9 to 1.2 mg O_2/mℓ sediment of the surface (0-2.5 cm) layer and from 1.2 to 2.4 mg O_2/mℓ sediment of the 5- to 10-cm layer in this study. Dechev et al.[18] measured SOD values per unit volume; the change in SOD with depth in the sediment differred from lake to lake although they measured only chemical oxidation (oxygen debt).

Oxygen uptake by the anaerobic sediments on a dry weight basis in Yunoko is shown in Fig. 2B. SOD of the surface sediment was more than 6 times as high as that of deeper sediments. SOD values of the surface sediments in Lake Kasumigaura ranged from 3.7 to 4.8 mg O_2/g dry sediment showing little difference between summer and autumn (see C_m values in Table 1 later on), whereas SOD of the surface sediments in Lake Yunoko showed larger values (29.0 and 16.9 mg O_2/g dry sediment) than that of Lake Kasumigaura (see also Table 1). In deeper layers any significant differences were not noted.

Rapid uptake of oxygen in the first 5 hours was observed for all samples. Fig. 3 shows decreases in dissolved oxygen concentration in sediment-water mixture of Lake Yunoko with and without cupric sulfate addition. Although the decrease in dissolved oxygen concentration by chemical oxidation could hardly be observed in the surface sediments (0-2.5 cm), a large amount of chemical oxidation within the first 1 hour was observed in the deeper sediment (7.5-10 cm). It must be noted that dissolved oxygen concentration decreased only by mixing sediment with water. Although biological oxidation cannot be ignored, rapid oxygen uptake within 1 hour seemed to originate mainly from chemical oxidation as pointed out by Dechev et al.[18] Wang[22] reported similar results where initial oxygen uptake rates of the sediments containing added chemicals were not significantly different from that of the control (without chemical addition).

First-order kinetics were applied to the oxygen uptake rate of the sediments as a first approximation. Assuming the maximum value of

the SOD, C_m (mg O_2/g dry sediment), the residual amount of oxygen uptake, S, was expressed by :

$$\frac{dS}{dt} = -K \cdot S \qquad (1)$$

where

$S = C_m - C$

C = cumulative value of oxygen consumed by 1 g of dry sediment at time t, mg O_2/g dry sediment

t = time, hr

K = oxygen uptake rate constant, hr^{-1}

From an analytical solution of Eq. (1), the following relationship can be derived :

$$\ln S = \ln C_m - K \cdot t \qquad (2)$$

C_m was estimated from C value levelled off where the rate of increase in SOD was less than 5 % per day (see MATERIALS AND METHODS). An example of the relationship between ln S and t is shown in Fig. 4. Three phases of oxygen uptake were noted. Although there were some exceptional cases (one or two phases, not shown here), three phases of oxygen uptake were generally observed in the sediment studies. It is plausible from these results that there are three components in SOD, among which the rate of oxygen consumption (K) is different from each other. Thus, C_m was divided into three parts:

$$C_m = C_c + C_1 + C_2 \qquad (3)$$

where

C_c, C_1, C_2 = maximum value of SOD for each component, mg O_2/g dry sediment

Applying first-order kinetics to each component, we get :

$$S = C_m - C = C_c \cdot e^{-K_c t} + C_1 \cdot e^{-K_1 t} + C_2 \cdot e^{-K_2 t} \qquad (4)$$

where

K_c, K_1, K_2 = oxygen uptake rate constant for each component, hr^{-1}

Assuming $K_c \gg K_1 \gg K_2$, three different linear relationships were derived. If t is large,

$$C_2 \cdot e^{-K_2 t} \gg C_1 \cdot e^{-K_1 t} \gg C_c \cdot e^{-K_c t}$$

Then we get :

$$\ln (C_m - C) \fallingdotseq \ln C_2 - K_2 t \qquad (5)$$

C_2 and K_2 can be determined from the plot of $\ln (C_m - C)$ vs. t. By using these values, the following equation can be counted when t is large :

$$\ln (C_m - C - C_2 \cdot e^{-K_2 t}) \fallingdotseq \ln C_1 - K_1 t \qquad (6)$$

C_1 and K_1 are able to be estimated from the plot of $\ln (C_m - C - C_2 \cdot e^{-K_2 t})$ vs. t. Similarly, C_c and K_c can be determined from the following relationship :

$$\ln (C_m - C - C_2 \cdot e^{-K_2 t} - C_1 \cdot e^{-K_1 t}) \fallingdotseq \ln C_c - K_c t \quad (7)$$

Values of SOD for each component, C_c, C_1, and C_2, and rate constants, K_c, K_1, and K_2, determined from Eqs. (5), (6), and (7) are summarized in Table 1. The ratio of rate constants, K_c/K_1 and K_1/K_2, ranged from 4 to 10. It can be concluded from the difference of K_c, K_1,and K_2 that 1st, 2nd, and 3rd phases of oxygen uptake by sediment samples (see Fig. 4) are mainly constitued by that of C_c, C_1, and C_2, respectively. Referring also to Fig. 3, the 1st phase seemed to correspond to chemical oxidation. Dubrawski and Lysiak[19)] reported two rate constants that correspond to K_c and K_1 in this study. Although reported values of K_c are slightly

low compared to these in this study for unknown reasons, similar ratios of K_c/K_1 (from 4.6 to 19.8) were presented. The first phase, chemical oxidation, was dominant for only a few hours followed by the 2nd phase that continued from 5 to 10 hours in this study. Bottom sediments in a eutrophic lake can be expected to contain a large amount of sedimented algae. Oxygen consumption by algal decomposition has also been reported to show 2 phases.[28)] Thus, it is likely that both the 2nd and the 3rd phases correspond to biological respiration with different rate constants.

The contribution of each phase of the total SOD, C_m, varied from sample to sample. In many of the sediment samples studied herein, C_m was fractionated into three components. In these cases the contribution of the second phase, C_2, was generally the smallest and ranged from 10 to 29 %. The value of C_c was generally equal to or smaller than that of C_1 in lake Kasumigaura where overlying water is always aerobic, whereas C_c showed greater values up to 70 % in anoxic sediments of lake Yunoko. Contrary to these results, unpolluted surface sediments (fine sands, of Lake Yunoko that were exposed by the dredging operation consisted mainly of C_2 and C_1 components which could not be differentiated.

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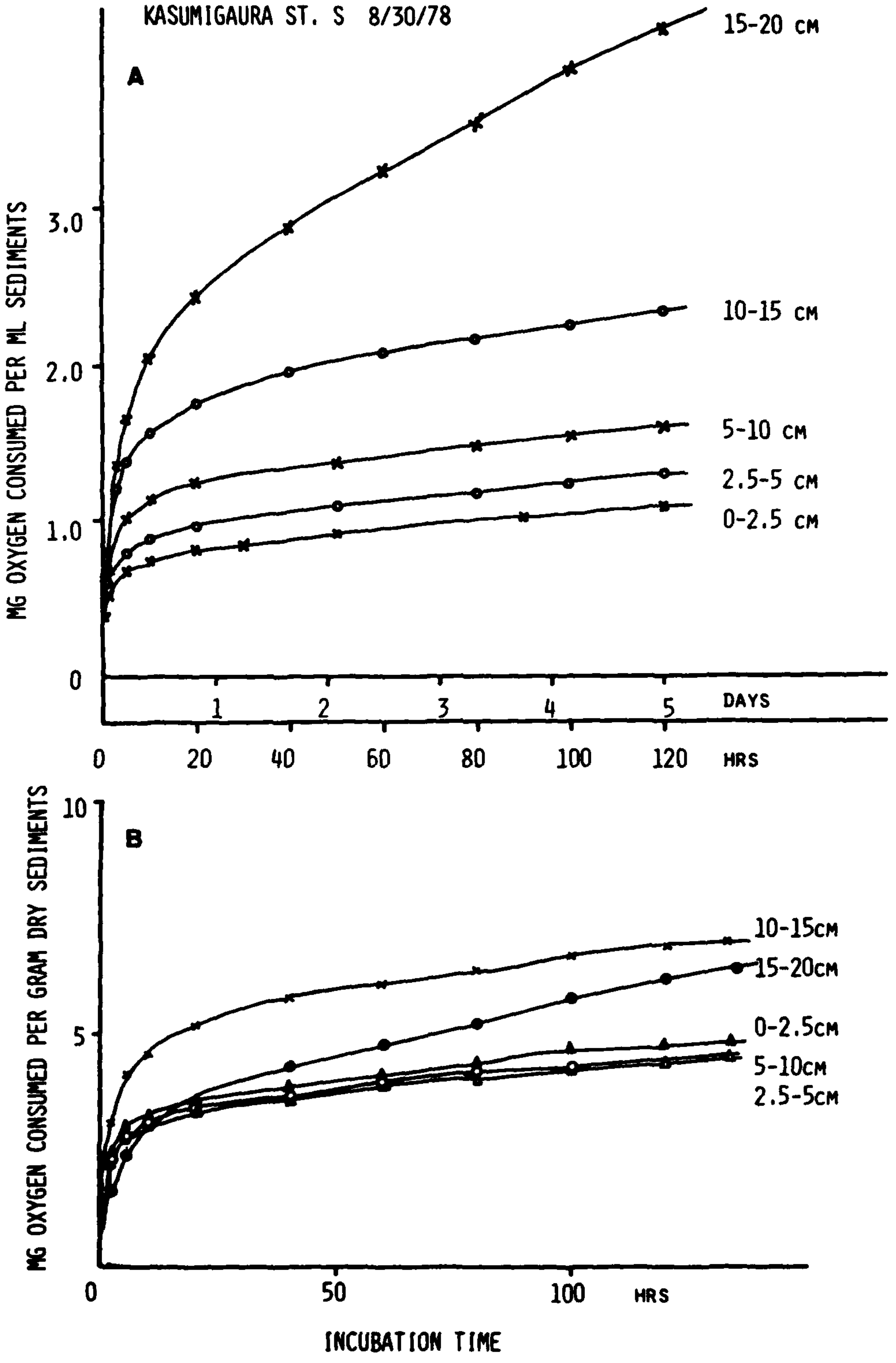

Fig. 1. Oxygen uptake by sediment samples with various depth in the bottom of Lake Kasumigaura (August 30, 1978) per 1 ml wet sediment (A) and per 1 g dry sediment (B).

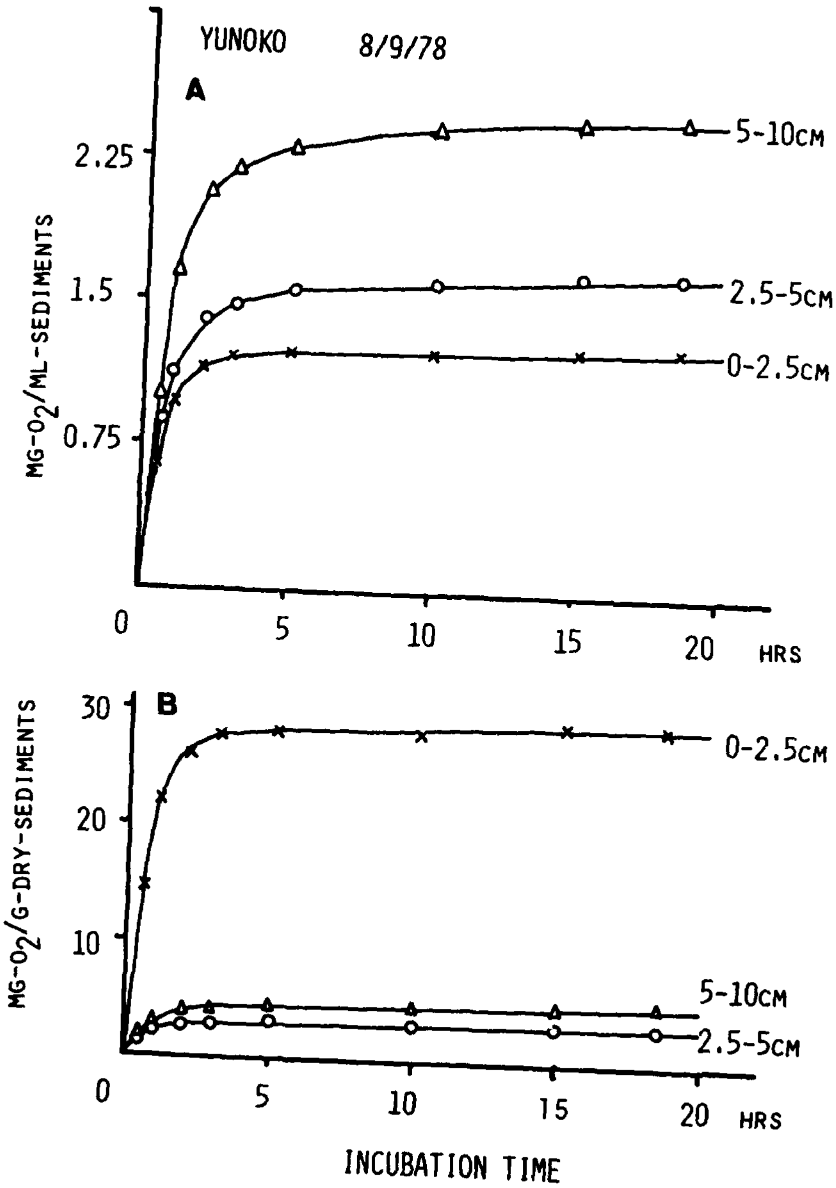

Fig. 2. Oxygen uptake by sediment samples with various depth in the bottom of Lake Yunoko (August 9, 1978) per 1 ml wet sediment (A) and per 1 g dry sediment (B).

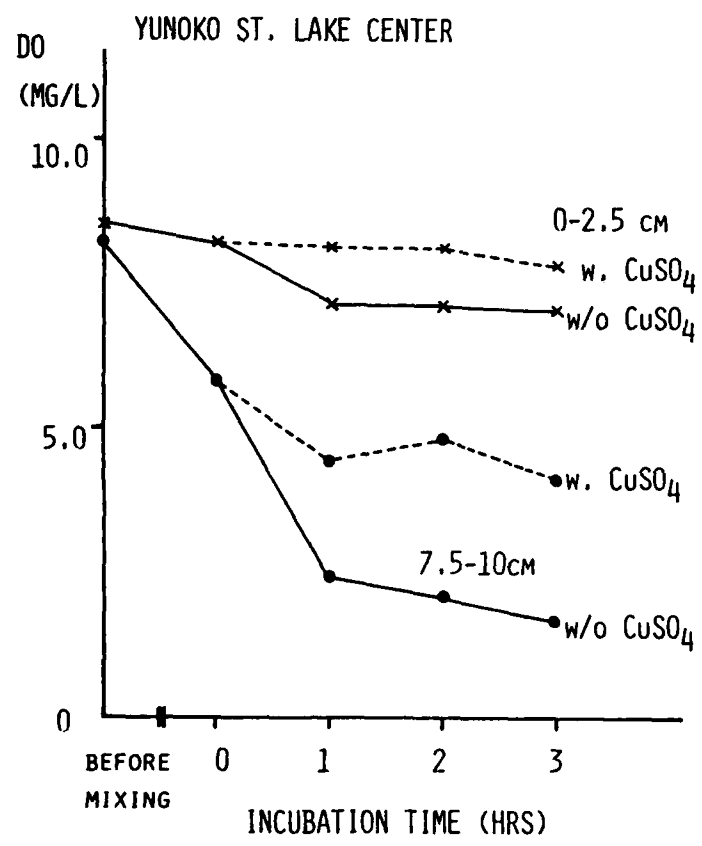

Fig. 3. Dissolved oxygen concentration in sediment-water mixture with and without chemical addition as dependent on time (Lake Yunoko, 10/18/78).

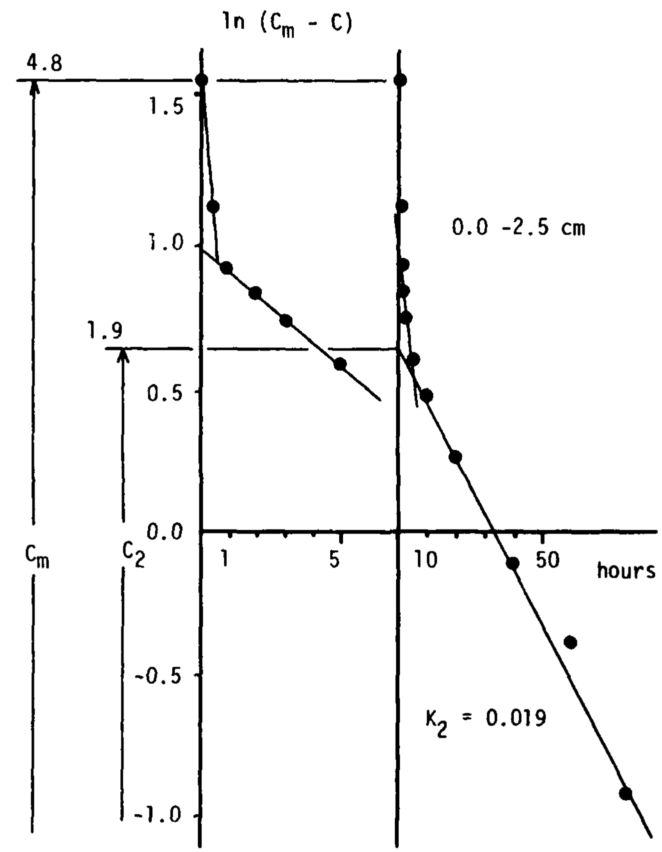

Fig. 4. ln S vs. t for the sediment of suface layer (0.0 - 2.5 cm, Lake Kasumigaura, 8/30/78). Solid lines are arbitrary.

Table 1. Kinetic fractionation of SOD. Values in the parentheses are percentage to C_m.

Sample	Depth (cm)	C_m (mg O_2/g dry sed.)	C_c	C_1	C_2	K_c	K_1 (hr^{-1})	K_2
Kasumigaura 8/11	0.0 - 2.5	4.0	1.1 (25)	1.0 (25)	2.0 (50)	0.7	0.098	0.0076
	5.0 - 10.0	6.5	2.2 (34)	1.2 (18)	3.1 (48)	0.38	0.036	0.0097
	15.0 - 20.0	12.4	1.9 (15)	1.3 (10)	9.2 (75)	0.17	0.020	0.0061
Kasumigaura 8/23	0.0 -2.5	4.2	1.9 (45)	0.8 (19)	1.5 (36)	0.48	0.086	0.025
Kasumigaura 8/30	0.0 - 2.5	4.8	2.1 (44)	0.8 (16)	1.9 (40)	0.65	0.084	0.019
	10.0 - 15.0	7.0	2.1 (30)	1.8 (26)	3.1 (44)	0.47	0.12	0.024
	15.0 - 20.0	6.4	1.3 (21)	1.3 (21)	3.8 (58)	0.19	0.043	0.015
Kasumigaura 10/14	0.0 - 2.5	3.7	1.1 (30)	0.8 (22)	1.8 (48)	0.49	0.13	0.014
	2.5 - 5.0	3.6	1.7 (47)	0.5 (14)	1.4 (39)	1.13	0.12	0.030
	5.0 - 10.0	4.2	1.8 (43)	1.0 (24)	1.4 (33)	0.88	0.20	0.018
	15.0 - 20.0	4.5	1.4 (31)	0.8 (18)	2.3 (51)	0.52	0.08	0.017

(Continued)

Table 1. (continued)

Sample	Depth (cm)	C_m	C_c	C_1	C_2	K_c	K_1	K_2
		(mg O_2/g dry sed.)					(hr^{-1})	
Yunoko 8/9	0.0 - 2.5	29.0	20.3 (70)	8.7 (30)	-	1.35	0.61	-
	2.5 - 5.0	3.5	2.4 (69)	1.1 (31)	-	1.17	0.26	-
	5.0 - 10.0	4.8	2.9 (60)	1.1 (23)	0.8 (14)	1.03	0.37	0.14
Yunoko 10/18	0.0 - 2.5	16.9	-	9.5 (56)	7.4 (44)	-	0.29	0.052
	2.5 - 5.0	2.5	1.2 (48)	0.7 (29)	0.6 (23)	0.55	0.14	0.037
	5.0 - 10.0	3.6	1.7 (47)	0.6 (17)	1.3 (36)	0.49	0.15	0.066
Yunoko 10/18 (tansuiken)*	0.0 - 2.5	5.6	-	1.1 (20)	4.5 (80)	-	0.13	0.051

* Dredged area

DREDGING AND NUTRIENT INACTIVATION AS LAKE RESTORATION TECHNIQUES: A COMPARISON

by

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ABSTRACT

Numerous lake restoration techniques are available. Most have not been evaluated thoroughly, so comparisons and conclusions cannot be drawn with any degree of reliability. This paper compares the dredging and nutrient inactivation techniques from the standpoint of identifying: (1) sources of the environmental problem; (2) purposes of the two techniques; (3) required sediment characterization; (4) problems associated with implementation; (5) equipment needs; (6) effectiveness of the methods; (7) cost of treatment; and (8) lake conditions best suited to the two methodologies. Based on these comparisons, nutrient inactivation appears to be more efficient than dredging in some instances where, theoretically, either treatment could achieve the same or similar in-lake finished project results.

INTRODUCTION

Eutrophication of freshwater lakes, common throughout the world, is often exemplified by massive growths of phytoplankton. Cause for these excessive growths is generally accepted to be an over-abundance of the major plant nutrients, nitrogen and phosphorus. Attempts at the restoration of phytoplankton-infested freshwater lakes have become relatively common since Sakamoto (1966) pointed out the relationships between phytoplankton-chlorophyll and total phosphorus concentrations, and since

Vollenweider (1968) first used these relationships to define his "critical phosphorus loading" levels. Design criteria based on these relationships, the passage of Public Law 92-500, and Federal authorization of several million dollars for lake restoration have produced numerous lake projects in the United States.

In spite of the enlightened guidance provided by Sakamoto and Vollenweider, not all lake restoration projects have resulted in success. This stems primarily from the fact that so many different restoration techniques have emerged, and because frequently implementation treatment is moving faster than understanding. Restoration techniques can be classified into three major categories (Table 1). Many have been used with little or no measure of their ability to control phosphorus inputs or their subsequent effects on the lake ecosystems. This is true particularly for the source control measures. Therefore, the benefits of source control have been more difficult to demonstrate than have the results of more direct in-lake treatment techniques. While in-lake treatment techniques are not necessarily better than source control techniques, the results are usually more immediate and apparent, thereby making them attractive to impatient users who want rapid, visible water quality improvements.

This paper compares dredging and nutrient precipitation/inactivation from the standpoint of: (1) identifying problem sources; (2) purposes of the two treatments; (3) sediment characterization requirements; (4) problems associated with the methods; (5) equipment; (6) effectiveness; (7) cost; and (8) lakes most suited to the two treatment techniques.

FACTORS RELEVANT TO A COMPARISON OF DREDGING AND NUTRIENT INACTIVATION

Identification of Problem Sources

An assessment of phosphorus and nitrogen plant nutrient sources must be undertaken prior to the implementation of any lake restoration project. This is best done by developing a nutrient budget which includes both external and internal nutrient contributions to the lake. The nutrient budget will identify the relative significance of various problem sources and permit the lake manager to focus attention on those problems which will yield the greatest return, in terms of water quality improvement, for the funds expended. Therefore, this is the most important step in any lake restoration project. Reckhow (1981) has completed an excellent review on the subject of lake data analysis and nutrient budget modeling.

TABLE 1. CLASSIFICATION OF LAKE RESTORATION TECHNIQUES*

I. Source Controls

1. Treatment of inflows
2. Diversion of inflows
3. Watershed management practices (land uses, cropping practices)
4. Lake use and user regulation (time and/or space proportioning practices for various uses
5. Product modification (detergents, pesticides)

II. In-Lake Controls

1. Dredging
2. Lake level drawdown
3. Dilution/flushing
4. Lake level stabilization
5. Nutrient inactivation/precipitation
6. Sediment sealing/covering
7. Shoreline modification
8. Selective discharge
9. Sediment oxidation via chemical application

III. Problem Treatment (directed toward treating symptoms rather than restoration per se)

1. Aquatic plant harvesting
2. Algicide-herbicide-pesticide application
3. Aeration
4. Mixing via lake bottom modification or pumping

* Modified from Porcella and Peterson (1977).

Assuming that an accurate assessment of the problem reveals that the major nutrient source is internal recycling, the two treatment techniques--dredging and nutrient precipitation/inactivation--can be examined more closely.

Purposes of the Two Treatment Methods

There may be numerous reasons for dredging a lake, but if the focus is on eutrophication control, then the primary function of dredging may be to: (1) deepen, thereby decreasing deep water temperatures, thus increasing dissolved oxygen concentrations for fish production; (2) remove nutrient-rich sediment, thereby reducing the tendency for internal nutrient recycling; or (3) remove rooted macrophyte beds, thereby reducing oxygen depletion problems, removing a potential nutrient source, and improving access for boating and fishing.

The purpose of nutrient precipitation (removal of phosphorus from the water column) or inactivation (long-term control of phosphorus release from the sediments) is directed solely toward the reduction of phosphorus in the water column to control the amount of planktonic algae (Cooke and Kennedy, 1981). Both techniques are accomplished by adding a chemical (usually aluminum sulfate) directly to a lake. The preferred method is addition of the chemical in slurry form just below the surface in whole-lake treatments or at some depth when treating the hypolimnion. According to Cooke and Kennedy (1981), the aluminum sulfate salts work by forming aluminum phosphate, by entrapping phosphorus-containing particles in the water column, and by the sorption of phosphorus to the surface of aluminum hydroxide. A white aluminum hydroxide floc forms in water as alum slurry is applied. The floc removes phosphorus as it settles to the bottom where it forms a blanket-like seal over the sediment. This seal tends to retard the recycling of phosphorus from the sediment. Within a few weeks, the "blanket" becomes incorporated into the sediment and visual evidence of its presence disappears.

Sediment Characterization Requirements

Prior to developing a final dredging plan to control nutrient recycling, it would be necessary to know nutrient concentration gradients with sediment depth to determine what thickness of sediment must be removed. It would also be necessary to know the areal extent of the increased nutrient concentrations. Given the strict criteria for disposing of dredged sediment under Section 404 (USEPA/Corps of Engineers, 1977) of United States Public Law 92-500, it may also be necessary to chemically characterize the sediment for toxic substances. Furthermore, it may be necessary to subject the sediment to a bioassay under 404 permit requirements.

In addition, a number of other factors need to be known about the sediment in order to design disposal areas. These include the bulk density, particle size distribution, COD, etc. Each of the data requirements takes time, requires a certain amount of expertise, and costs money.

To treat the sediment with a nutrient inactivant, on the other hand, requires only limited knowledge of the sediment. One needs to know if it is a nutrient source. There is no special reason to establish the phosphorus content of the sediment, since the lake is usually treated as a whole and since the concentration of inactivant applied is dependent more on characteristics of the water than the sediment itself (see section on treatment techniques). No stoichiometric assumptions are made about the inactivant and sediment phosphorus concentrations. This does not imply that these relationships should not be developed, but simply reflects the current state-of-the-art. If hypolimnetic treatment is preferred, the treatment area can be determined with relative ease by measuring dissolved oxygen profiles and consulting a bathymetric map of the lake. As currently practiced, far less sediment information is required for nutrient inactivation than for dredging.

Problems Associated with the Treatment Methods

Peterson (1979, 1981) discussed a number of environmental concerns associated with sediment removal. The most common is the liberation of nutrients or toxicants from the bottom sediments to the water column as fine material is resuspended. In the case of nutrients, this affect appears to be short-lived and of limited ecological consequence (Dunst and Beauheim, 1979). If, however, toxic or hazardous materials are contained in the sediment, they may pose a serious bioaccumulation problem to aquatic organisms and to man if he consumes the contaminated organisms.

Carline and Brynildson (1977) pointed out that important fish food organisms may be eliminated for 2 to 3 years after dredging if small lakes are dredged completely during a single growing season. Andersson et al. (1975) found that when dredging was conducted over a longer period of time (2 years) in a larger lake the benthic population was less likely to be destroyed. Andersson and Carline both indicated that benthic reestablishment may be almost immediate if portions of the lake were left undredged.

Another problem associated with dredging freshwater lakes is disposal of the dredged material. As mentioned previously, disposal of dredged material usually requires a Federal dredged material disposal permit (a 404 permit) and extensive testing of the dredged material may be necessary to obtain the permit. The analyses themselves may cost several thousand dollars and a time delay which usually adds to the overall project expense. Beyond the permitting problem itself, it is becoming increasingly difficult to locate suitable dredged material

disposal sites. A major reason is that Federal law prohibits the indiscriminate filling of lowlands and wetlands. This forces the water quality manager to seek upland disposal sites.

Many lake sediments are suitable for topsoil dressing because of their high nutrient content. However, most farmers are unwilling to allow direct pumping to their fields because it requires removing land from production while the dredged material dewaters. Therefore, an interim disposal site must be found. This requires another piece of land, usually extensive construction of containment dikes, and rehandling of the dredged material. All increase the cost of disposal.

An extreme example of a disposal problem was encountered in the recent dredging of a small, urban lake in New York City. There was no disposal area within a reasonable pumping distance from the lake. Therefore, the dredged material was pumped to tanker trucks and hauled out of the city. The disposal problem increased dredging costs above an average $1.60/m^3 (n = 12) to approximately $14/m^3 (Peterson, 1979). The volume of material removed was about 14,000 m^3, thus the project dredging costs amounted to $196,000, or approximately $109,000/ha to dredge the lake.

A recent review of the nutrient inactivation lake treatment technique by Cooke and Kennedy (1981) indicates that no Federal permits are required (some states may require permits) for lake treatment using this approach. There are no disposal problems associated with the method. Out of the 28 case histories of nutrient inactivation treatments reviewed by Cooke and Kennedy, there was only one reported "possiblity" of aluminum toxicity to microcrustacea. There was also one reported instance of decreased microcrustacea diversity. No other side effects were reported. Funk et al. (1975) indicated that macrocrustacea were unaffected by alum treatment at Liberty Lake, Washington. Disruption of lake usage is minimal with alum treatment, and there are no restrictions on subsequent water use.

Equipment Required

Chemical characterization of sediment prior to dredging requires specialized equipment. Special equipment is also required for sediment sampling and preparation prior to chemical analysis. Dredging itself requires a sizable capital outlay for either purchasing or leasing a dredge. The dredge may be needed for 2 or 3 months or 2 or 3 years (Peterson, 1981), depending on the job. Dredging may require booster pumps, trucks, and additional maintenance equipment. Where disposal site preparation is required, earth movers and equipment operators will be needed.

Chemical dosage determination for the nutrient precipitation/ inactivation technique requires limited laboratory equipment. One of the simplest methods for determining the chemical treatment level

required to remove phosphorus from the water column (nutrient precipitation) involves jar tests (Peterson et al., 1974). In this procedure, the alkalinity, pH, and phosphorus levels of a lake water sample are measured. The sample is then proportioned into a series of test jars to which varying doses of the nutrient inactivant are added, mixed, and the floc allowed to settle. The phosphorus content of the water is then measured again and the percent removal is determined. Data from the jar tests are used to calculate the molar ratio of Al:P which is required to remove the desired amount of phosphorus from the lake. This calculation determines the amount of nutrient inactivant that must be added to attain phosphorus control in the water column of the lake.

To achieve optimum sediment sealing (nutrient inactivation) benefits from an alum treatment, considerably more chemical must be added to a lake than that which is required to remove phosphorus from the water column. However, no firm relationships have been established between higher alum treatment levels and increased length of treatment effectiveness. Cooke et al. (1978) have suggested that maximum sediment sealing benefits might be achieved by adding as much alum as possible to a lake without exceeding a water column residual dissolved aluminum (RDA) concentration of 50 µg Al/l. Everhart and Freeman (1973) reported that 50 µg Al/l of RDA was the level considered safe to protect rainbow trout from toxicological effects. The RDA concentration is largely pH-dependent and therefore a function of lake water alkalinity. A method for determining the alum "maximum safe treatment" concentration for lakes, based on total alkalinity concentration, has been described by Kennedy (1978) and by Kennedy and Cooke (1981). To date, nutrient inactivation treatment concentrations usually have been somewhere between the minimum required for precipitation and the maximum safe treatment level aimed at sealing the sediments.

The equipment requirements for nutrient inactivant application are relatively simple. They consist of shoreside tanks and mixing devices to produce an alum slurry unless premixed slurry can be tank-trucked to the site. Actual application usually is accomplished by pumping the inactivant slurry from storage tanks on a barge through a distribution manifold either below or behind a barge. Churning of the water from the barge wake and motor propellers provides the necessary mixing to produce an alum floc. Gasperino (1981) indicated that pressure created by pumping alum slurry through a distribution manifold was more than adequate to mix the material in the water column and also serve as a means of propelling the distribution barge. A possible disadvantage to this technique is that currently there are no commercially produced nutrient inactivant application apparatuses available. The relative simplicity of the equipment, however, should not prevent an interested lake manager from assembling the necessary hardware.

Effectiveness of the Two Techniques

The expected results of dredging include improved dissolved oxygen concentration; less sediment-water nutrient exchange accompanied by reduced algal biomass and increased water clarity; and reduced macrophyte nuisance problems. In practice, not all of the expected results are realized. However, Peterson's (1981) review of 65 lake dredging projects found that 22 were considered generally successful. Another 10 were still in progress, 14 were in the planned stage, while 17 provided no indication of their success. Only two projects were considered unsuccessful and these failures were attributed to continued high external nutrient inputs to the lakes.

Lilly Lake, Wisconsin, illustrates the short-term changes in lake nutrient and productivity levels which may result when dredging is initiated. Figure 1 shows that total inorganic nitrogen concentrations increased dramatically over background levels when dredging began in July 1978. The initial increase peaked in the fall about the time dredging stopped for the winter and showed a steady decline from that point throughout the next summer dredging period. Total phosphorus concentrations showed no major changes during dredging compared to the predredging concentration (Figure 2). Oxygen concentrations during dredging also remained similar to those during the predredging years (Figure 3). Winter oxygen depletion was just as evident after the first year of dredging as it was before dredging.

Chlorophyll a concentrations increased dramatically as dredging began in 1978 (Figure 4) and they continued to be higher during active dredging in 1979 compared to the 1977 predredging levels. Table 2 shows summer (July - September) means for water quality variables at Lilly Lake before, during, and after dredging. Although the project is considered highly successful in terms of increased lake recreational use and minimal environmental impact, the short range evidence of success in terms of improved water quality is somewhat less apparent. It should be noted, however, that the first objective of dredging at Lilly Lake was to deepen the lake. A secondary objective was to control the internal recycling of plant nutrients. Continued monitoring will provide a better idea of the project's longer range effectiveness.

Lake Trummen, Sweden, remains the best example to date of distinct, immediate, and long-range water quality benefits derived from dredging. This project was undertaken specifically to reduce internal nutrient recycling. Figure 5 shows that reduced nutrient concentrations were realized almost immediately and that they have lasted beyond project completion. The reduced nutrient concentrations were accompanied by significant reductions in chlorophyll a concentrations (Peterson, 1981). Improved oxygen concentrations were not mentioned specifically; however, they were implied by Bjork (1974) when he described improved fishing, swimming, and other recreation in the lake. Ripl (1980) reports that water quality in Lake Trummen is still very good 9 years after dredging.

TABLE 2. SUMMER MEANS OF BEFORE, DURING, AND AFTER IN-LAKE CONDITIONS FOR SELECTED VARIABLES IN LILLY LAKE, WISCONSIN. MEANS ARE BASED ON BIWEEKLY SAMPLING PROCEDURES (MODIFIED FROM DUNST AND JANES, 1980).

	Before		During		After
Variable	1976	1977	1978*	1979*	1980*
Ammonia-N (mg/l)	---	0.03	1.12	1.44	0.05
Organic-N (mg/l)	---	1.5	1.8	1.4	1.1
Soluble reactive phosphorus (μg/l)	---	<4	<4	<4	<4
Soluble organic phosphorus (μg/l)	---	10-17	6-10	5-9	3-7
Particulate phosphorus (μg/l)	---	7-15	29	19	11
Chlorophyll a (μg/l)	2.5	3.3	18.5	9.5	5.9

* Prior to dredging (1977), maximum lake depth was 1.8 m, thus for comparative purposes the 1978, 1979, and 1980 values represent the top 1.8 m of the lake.

The Lake Trummen project was preceded by wastewater diversion. Although one cannot compare Lake Trummen and Lilly Lake directly, they demonstrate that results of dredging may vary considerably from project to project.

With alum-induced nutrient inactivation, the results are almost always more rapid and more evident than those for dredging. The primary reason is that most lakes can be chemically treated in 2 or 3 days. The nutrient inactivant acts almost immediately and water quality improvements frequently are evident within a few days. Figures 6 and 7, respectively, illustrate the rapid declines in dissolved reactive phosphorus and total phosphorus that were attained in Mirror Lake, Wisconsin, when it was treated with 6.6 g Al/m^3 of lake water. Figures 8 and 9, respectively, show that alum treatment has little impact on NO_2-NO_3 nitrogen or dissolved oxygen concentrations. Deep water oxygen concentrations were maintained at Mirror Lake before and after alum treatment only by supplemental aeration. Figure 10 illustrates the reduced chlorophyll a concentrations in Mirror Lake in 1978 following the alum treatment and the residual effectiveness of the treatment during the 1979 growing season. Knauer and Garrison (1980) indicated that total phosphorus and dissolved reactive phosphorus in the epilimnion of Mirror Lake were < 20 μg/l and undetectable, respectively, during the summer of 1980.

Some lakes have shown relatively short-term benefits (1-2 years) following alum application. These are usually shallow lakes or those which received no watershed modifications in conjunction with the alum treatment (Cooke and Kennedy, 1981). Very few nutrient inactivation

lake restoration projects have been satisfactorily monitored over time to determine the longevity of treatment effectiveness. However, one of the best examples is demonstrated by the Twin Lakes, Ohio, project (Cooke and Kennedy, 1981). This project was conducted in 1975 as a research demonstration, and provides particularly good evidence of alum treatment effectiveness (Figure 11). After 6 years, water quality of the treated lake remained vastly improved over its pretreatment condition. The untreated lake (East Twin Lake) has improved somewhat over the same time period. Cooke (1981) attributes this to the fact that the untreated lake is downstream, has a 0.6- to 0.7-year hydraulic residence time, and receives 50% to 70% of its inflow from the treated lake. In other words, secondary benefits to East Twin Lake were derived from the treating of West Twin Lake. This project demonstrates that in-lake nutrient inactivation can be effective over extended periods of time (at least 6 years) if enough inactivant is added to retard phosphorus release from the sediments and if external nutrient supplies are an insignificant part of the total input.

Cost

Peterson (1979, 1981) has described the difficulty in calculating a representative cost for dredging freshwater lakes. Variation is attributed to differences in project size, sediment type, equipment type, dredging depth, disposal area distance from the dredge site, and several other factors. Cooke and Kennedy (1981) have indicated that problems in developing representative unit costs for alum treatments are due mainly to variations in the lake area, chemical costs, labor costs, and the amount of chemical required to control in-lake nutrient cycling.

Given the inherent problems associated with calculating representative treatment costs for either technique and the fact that dredging costs usually are calculated on a per cubic meter basis while nutrient inactivation costs usually are on a per hectare basis, the direct comparison of costs between the two techniques is difficult. However, if we assume that both techniques are directed toward the control of in-lake phosphorus cycling and that the treatment cost in either case is that considered necessary to control the cycling, then one could compute a cost comparison on the basis of phosphorus removed (dredged material) and phosphorus inactivated (sealed into the sediment). Unfortunately, the data necessary to compute these figures are not readily available. In lieu of the necessary sediment chemistry and depth profile data, I have assumed that dredging costs for nutrient control projects (not deepening projects) presented by Peterson (1981) are based on the amount of sediment, and consequently the amount of phosphorus, thought necessary to be removed to control in-lake nutrient cycling. Therefore, I have used the cost per cubic meter, the area of the lake, the percentage of the lake basin dredged, and the volume of dredged material to compute a per hectare dredging cost. The accuracy of these calculations is ± \$5.00/ha.

The per hectare dredging costs for 11 projects (ones with sufficient data to compute costs) from Peterson (1981) are listed in Table 3 with six nutrient inactivation project costs. The nutrient inactivation costs are accurate to ± $5.00/ha. The individual nutrient inactivation project costs in Table 3 are based on materials cost and time required (man-years) from Cooke and Kennedy (1981), and my assumption of 8-hour days at $5.00/hr. The nutrient inactivation cost in Table 3 does not include equipment, but as previously indicated in this paper, equipment costs for alum treatments are relatively small compared to the other costs ($16,400 or 9% of total project cost at Medical Lake, Washington).

TABLE 3. PER HECTARE COST OF IN-LAKE PHOSPHORUS CONTROL BY DREDGING AND NUTRIENT INACTIVATION. COSTS ARE ON THE BASIS OF INDIVIDUAL PROJECTS AND SHOWN IN DOLLARS/HA.

	Dredging Cost	Nutrient Inactivation Cost
	2,000	155
	4,000	258
	5,000	426
	5,000	582
	7,000	1,020
	11,000	1,740*
	13,000	
	16,000	
	19,000	
	28,000	
	39,000	
Mean	13,600	696

* Medical Lake, Washington (Gasperino et al., 1981).

The abnormally high cost for treating Medical Lake, Washington (Table 3), is due mostly to the amount of chemical required ($90,000 = 935 metric tons of aluminum sulfate). The lake is relatively deep (z_{max} = 18 m, $\bar{z}$ = 10 m),* has a large volume (6.2×10^6 m^3), and has an uncommonly high total alkalinity (approximately 750 mg/l as $CaCO_3$). Each of these factors adds to the required amount of nutrient inactivant needed to reduce the dissolved reactive phosphorus (DRP) concentration by the targeted amount. An 87% reduction in DRP was considered necessary to control phytoplankton growth. Other than this one case, the cost of nutrient inactivation compared to dredging is most reasonable. It is

* z_{max} = maximum depth; $\bar{z}$ = mean depth.

evident from Table 3 that maximum treatment cost per hectare for nutrient inactivation does not even approach that for dredging. In fact, when Medical Lake treatment cost is removed from the computation, the mean cost of the remaining five projects ($488/ha) is less than one fourth of the minimum reported dredging cost on a per hectare basis.

Lake Conditions Most Suited to Each Technique

Lake conditions favorable to dredging for nutrient control generally include watershed control measures, organically rich sediment, low sedimentation rates, long hydraulic residence time (6 months or more), and shallow depths. Lake conditions contributing to successful nutrient inactivation treatments according to Cooke and Kennedy (1981) include watershed control measures, moderate to low detention times (several months or longer), and moderate alkalinity (80-200 mg/l $CaCO_3$). It can also be presumed that organically rich sediment and low sedimentation rates might be conditions prerequisite to nutrient inactivation. Although the review of nutrient inactivation by Cooke and Kennedy (1981) does not address depth as a factor influencing the effectiveness of nutrient inactivation, these authors and others (Knauer and Garrison, 1981) have expressed reservations about use of this technique in shallow lakes which may be polymictic.

Most of the lake conditions favorable to dredging are also suitable to nutrient inactivation. The only apparent divergence pertains to depth. According to Peterson (1981), the mean depth of lakes dredged to control in-lake nutrient cycling ranged from 0.3 m to 7.6 m ($n = 27$) and averaged 1.9 m. The mean depth of lakes subjected to nutrient inactivation ranged from 1.5 m to 10.0 m ($n = 17$) and averaged 4.0 m according to data from Cooke and Kennedy (1981). The two shallowest lakes reported by Cooke and Kennedy (1981) to have benefited from alum treatment had mean depths of 4.0 m and 2.4 m. The treatment effects for these two lakes lasted 2-3 years and 1 year, respectively. The duration of effectiveness, however, was related more closely to uncontrolled watershed inputs than to the depth of these lakes. The effect of depth on the longevity of alum treatment effectiveness remains unclear. Water depth per se is probably less important than its potential to influence stratification stability. In this respect other physical factors such as temperature, wind velocity, and fetch may be more significant than depth in determining the duration of alum treatment effectiveness. It has been suggested by Stefan and Hanson (1981) that these same factors are very important in determining the effectiveness of dredging to control in-lake nutrient cycling.

CONCLUSIONS CONCERNING THE COMPARISON BETWEEN DREDGING AND NUTRIENT INACTIVATION

1. Problem assessment in terms of a detailed nutrient budget is essential to the success of any treatment technique.

2. Dredging attempts to remove the in-lake source (sediment) of the nutrient recycling problem. Nutrient inactivation attempts in-place control of the problem by sealing the sediments against nutrient exchange with the overlying water. Both treatment methods seek to make phosphorus limiting to phytoplankton growth.

3. Neither treatment method will be highly successful unless attempts have been made to control significant sources of watershed nutrient supplies.

4. The amount and kind of data required to develop a dredging plan are generally more voluminous and difficult to obtain than that required for a nutrient inactivation plan. Consequently, problems associated with dredging projects are generally more complex.

5. While dredging equipment is more available commercially than is the equipment for nutrient inactivation, it generally requires a much greater capital outlay.

6. Both treatment techniques have been reported to be generally successful in the short run (1-2 years). The results of nutrient inactivation are usually observed sooner and the results are more obvious than for dredging. Insufficient observation of the two treatment methods over extended periods of time makes it difficult to generalize about long-term effectiveness. The two best examples of long-range effectiveness put dredging (Lake Trummen, Sweden) at 9 years and nutrient inactivation (Twin Lakes, Ohio) at 6 years.

7. Dollar-for-dollar cost comparisons of the two techniques to control equivalent amounts of phosphorus are impossible. However, mean dredging costs on a per hectare basis exceed those of nutrient inactivation by approximately 20 times.

8. Lake conditions most suitable to the two techniques are quite similar with the possible exception of depth. Dredging is usually done in very shallow lakes, while nutrient inactivation is conducted in moderate to moderately deep lakes. However, there is a significant amount of overlap in lake conditions required to maximize the benefits of the two treatment methods.

9. Considering the above factors, nutrient inactivation might be more efficiently employed than dredging in selected cases and should be weighed seriously against dredging in all but very shallow (less than 3 m) lake systems contemplated for in-lake nutrient control measures.

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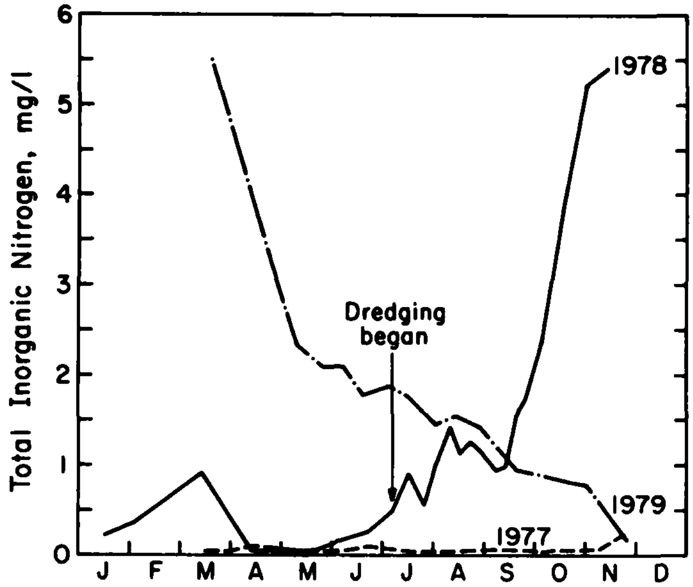


Figure 1. Lilly Lake, Wisconsin, total inorganic nitrogen, mean concentration grom the 0.5- and 1.5-m sampling depth (data from Dunst and Beauheim, 1979).

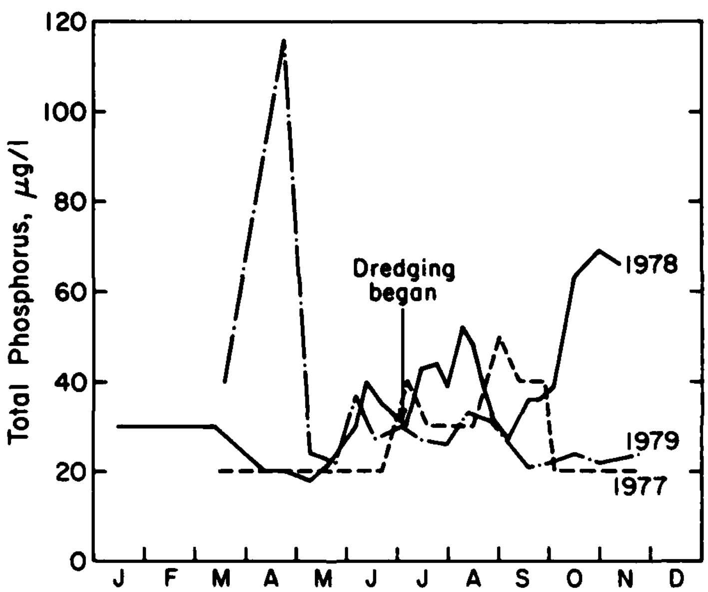


Figure 2. Lilly Lake, Wisconsin, total phosphorus, mean concentration from the 0.5- and 1.5-m sampling depth (data from Dunst and Beauheim, 1979).

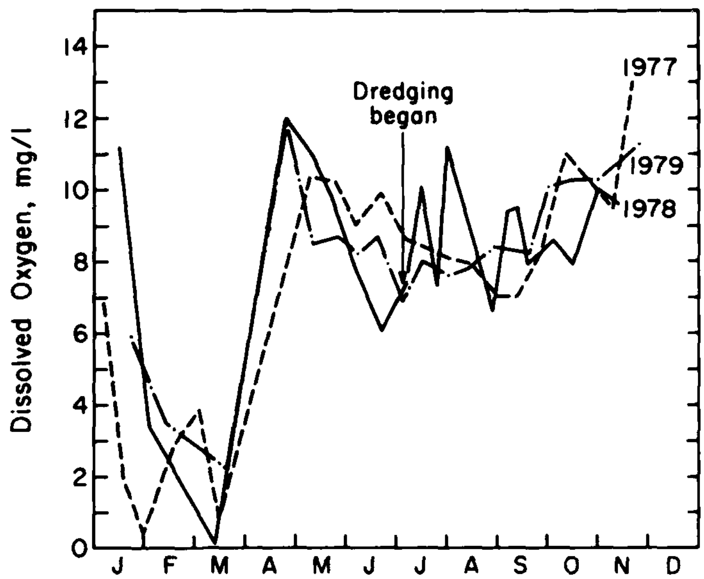


Figure 3. Lilly Lake, Wisconsin, dissolved oxygen, mean concentration from the 0.5- and 1.5-m sampling depth (data from Dunst and Beauheim, 1979).

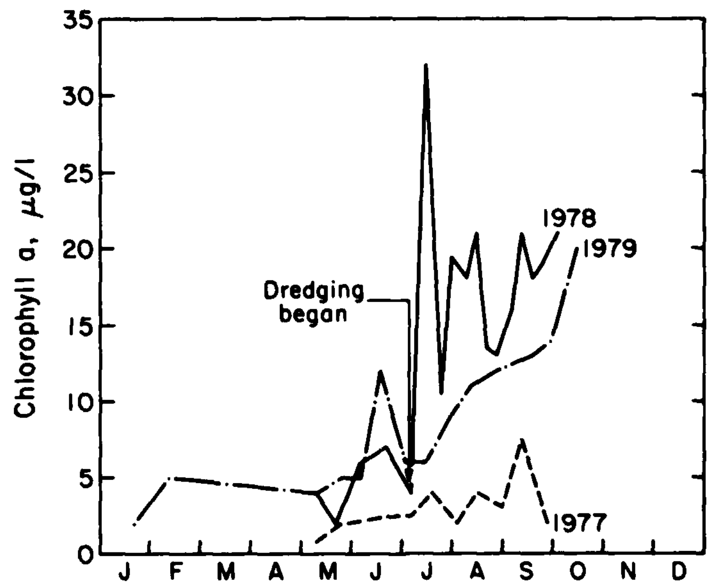


Figure 4. Lilly Lake, Wisconsin, chlorophyll a, mean concentration from the 0.5- and 1.5-m sampling depth (data from Dunst and Beauheim, 1979).

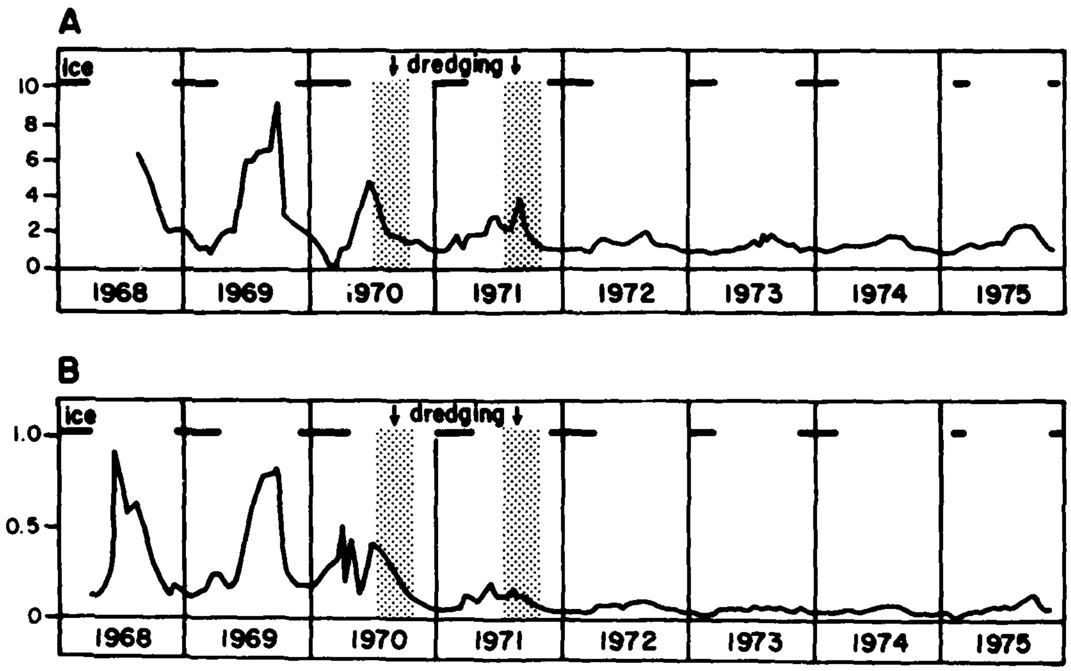


Figure 5. Lake Trummen, organic nitrogen (A, mg N liter^{-1}) and total phosphorus (B, mg P liter^{-1}) in surface water, 1968-1975 [data from W. Ripl, 1980 (modified from Bjork, 1978)].

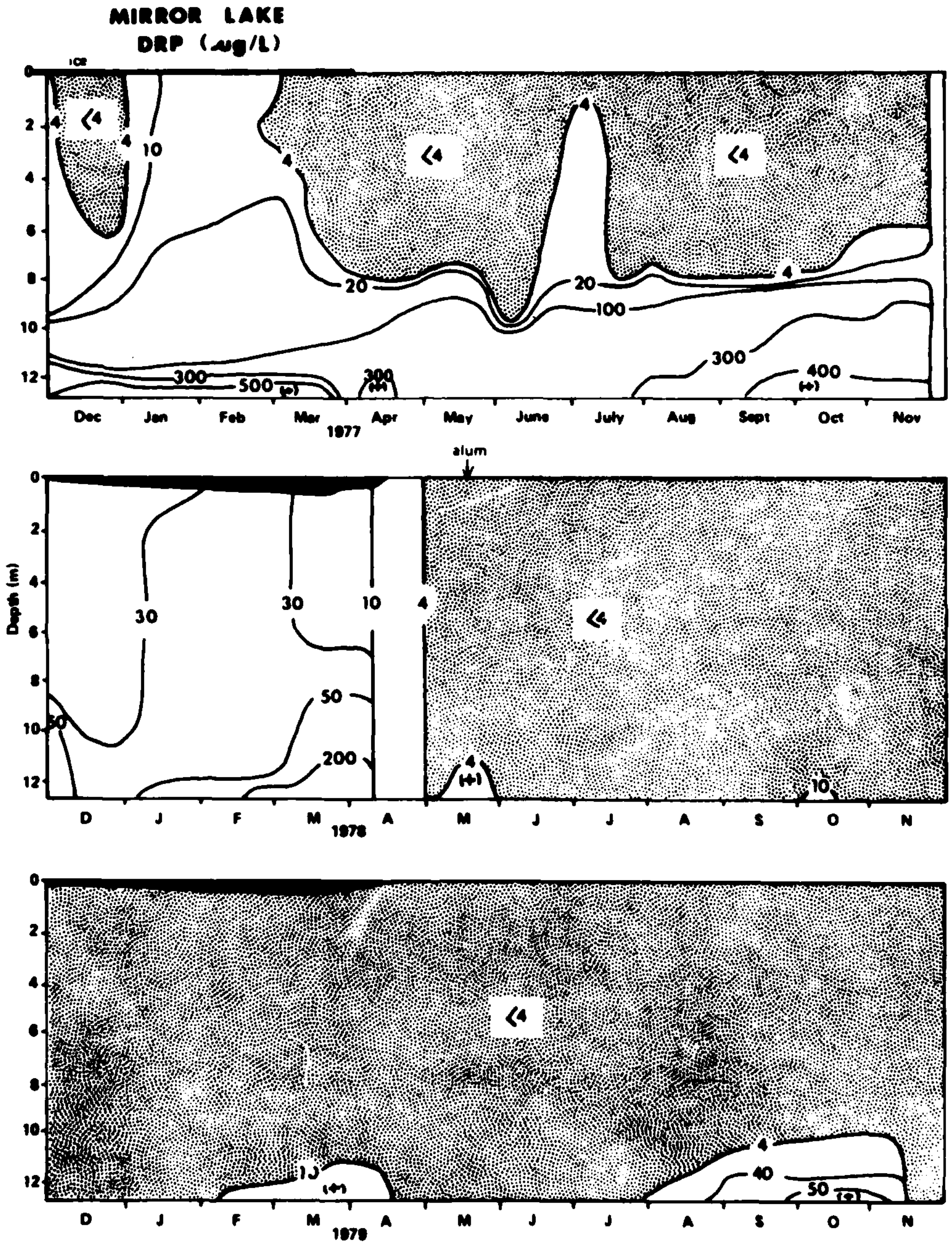


Figure 6. Mirror Lake, dissolved reactive phosphorus (µg/l) (from Garrison, 1980).

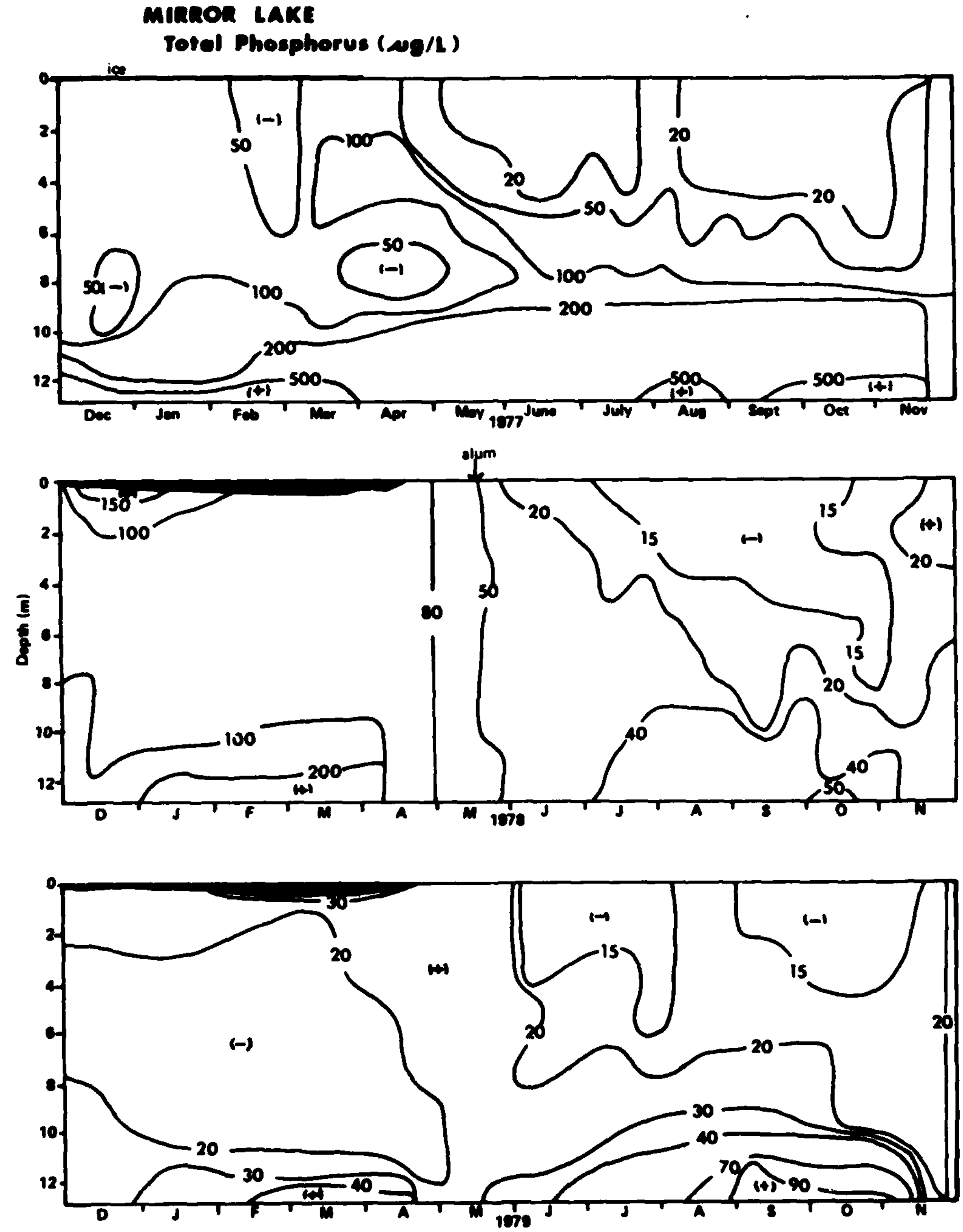


Figure 7. Mirror Lake, total phosphorus (µg/l)
(from Garrison, 1980).

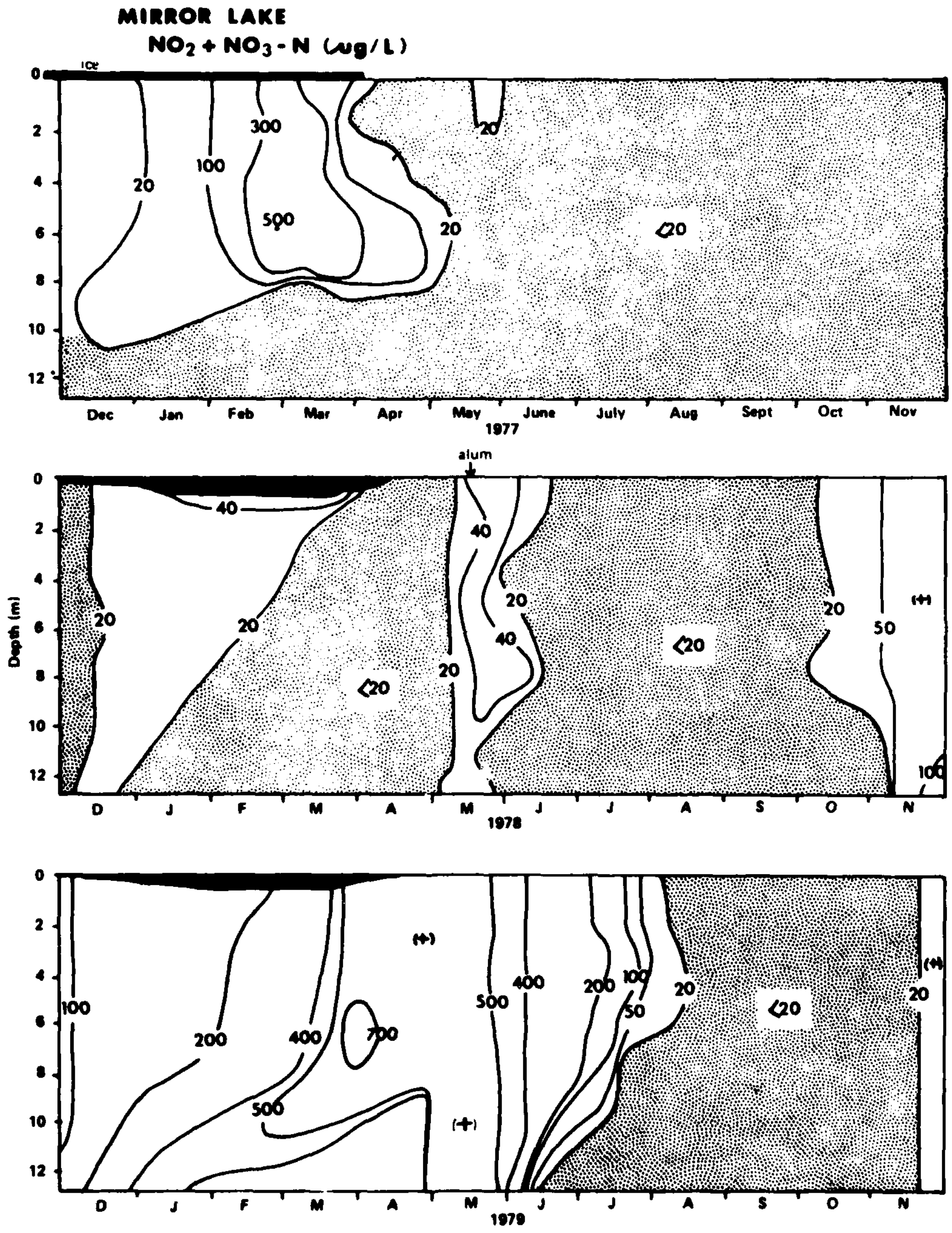


Figure 8. Mirror Lake, nitrite and nitrate nitrogen (µg/l) (from Garrison, 1980).

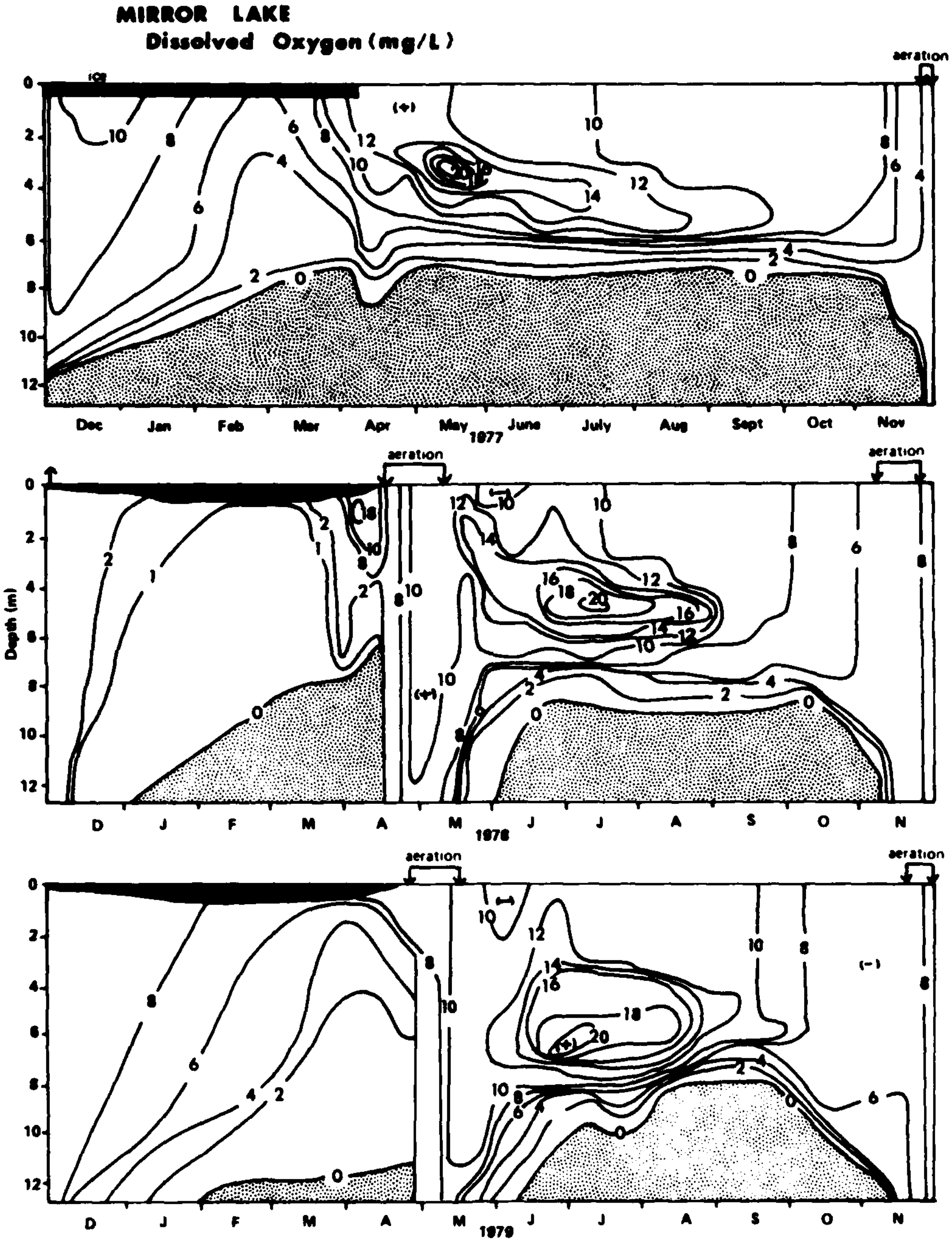


Figure 9. Mirror Lake, dissolved oxygen (mg/l) (from Garrison, 1980).

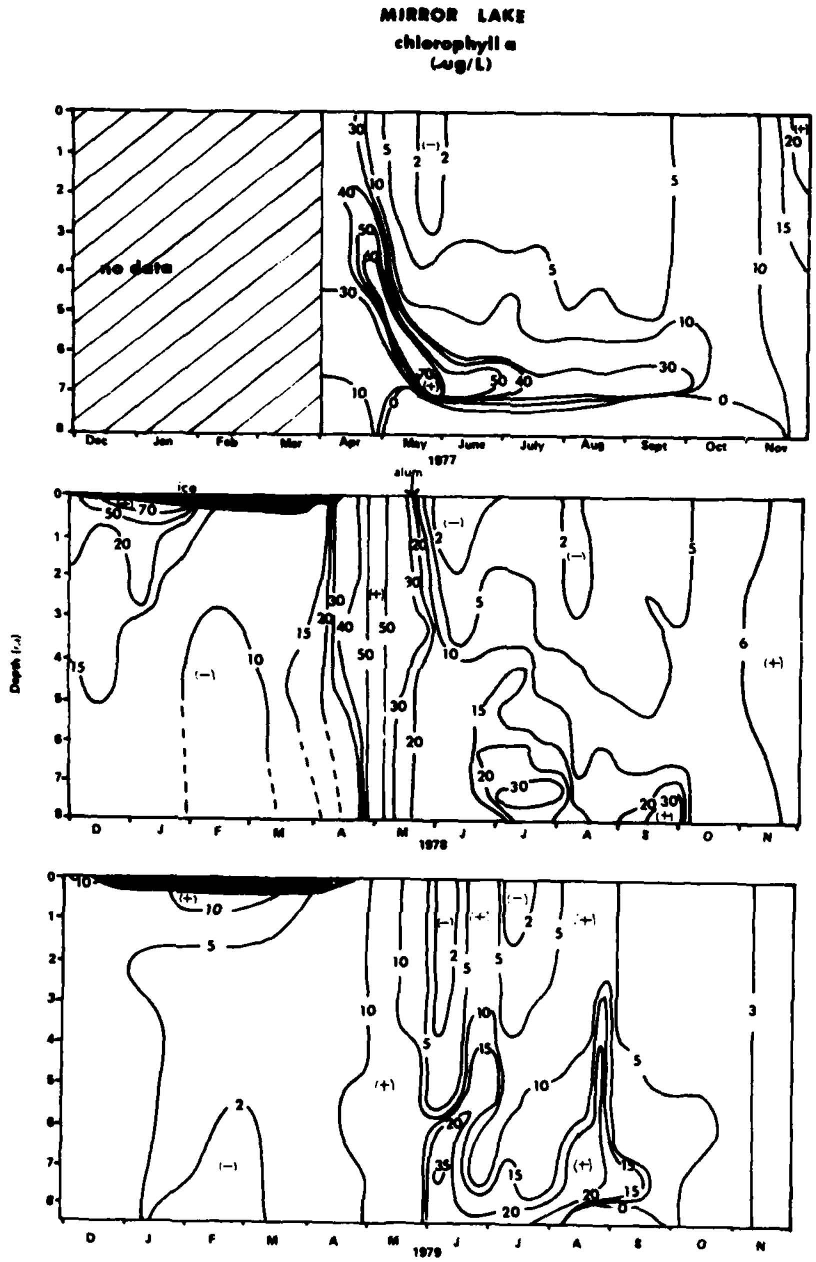


Figure 10. Mirror Lake, chlorophyll a (μg/l) (from Garrison, 1980).

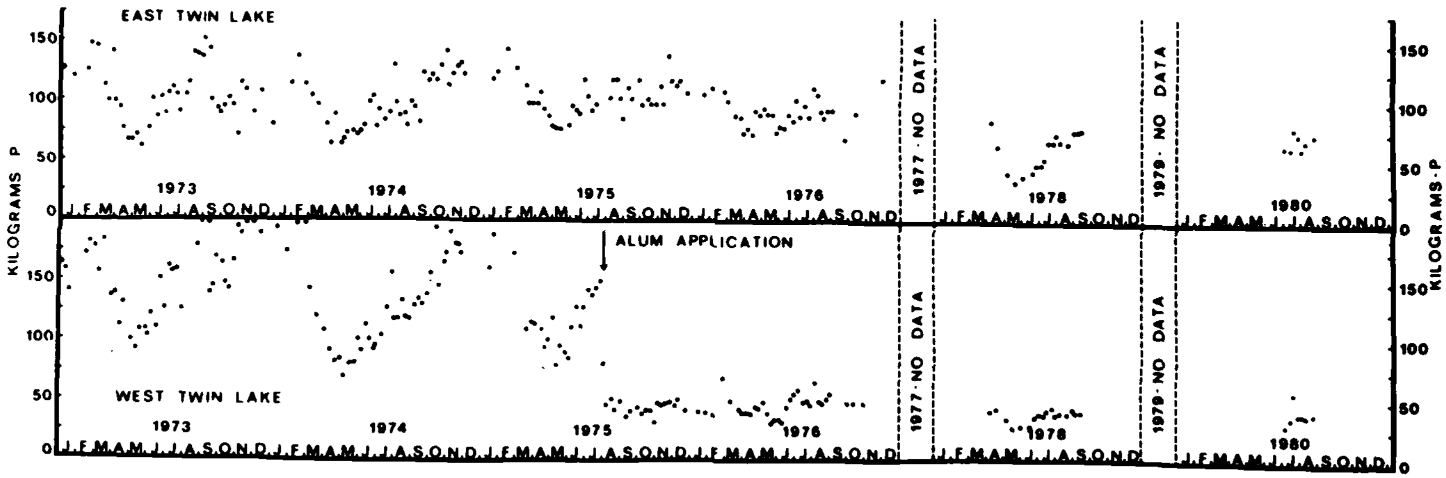


Figure 11. Phosphorus content (kilograms-P) of East and West Twin Lakes (from Cooke et al., 1981).

EFFECTS OF EXTERNAL AND INTERNAL LOADING OF POLLUTANTS UPON WATER QUALITY

DR. T. YOSHIDA
Japan Bottom Sediments Management Association

ABSTRACT

This paper deals with the problem of how the inflow and release of pollutants affect water quality in areas like harbours, bays, and lakes. When studying water pollution, comprehensive measurements are generally performed, but the relationships between inflowing and release quantities of pollutants and their concentrations in water are not always clear. This paper studies the relationships from the point of view of hydrostatical mathematics. It introduces the theory that the concentrations of nutrients in water areas where they are released from sediment should be vertical in a special profile. If we ascertain this vertical profile, we can estimate the release rates of nutrients. At the same time, this paper describes the concentrations of inflowing pollutants in the water.

1. Vertical Distribution of Nutrient Concentrations in Water

During a study of the water pollution at Hachinohe Harbour, the water quality was measued at 5 points as shown in Fig. 1.

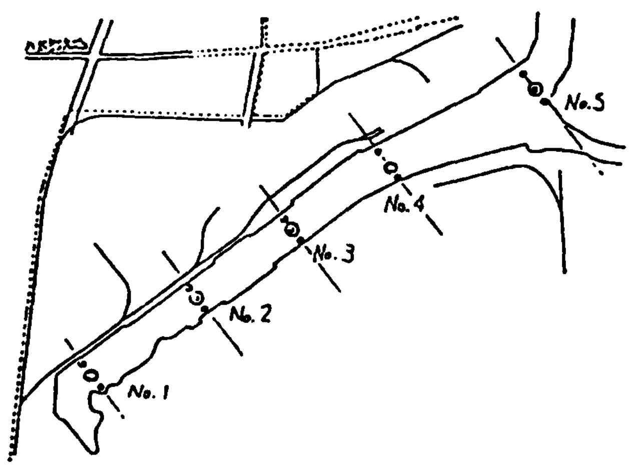


Fig. 1. Measuring Points in Hachinohe Harbour

From the observations it was found that nutrient concentrations in the upper layers were distinctly large, and were small in the deeper layers, as shown in Fig. 2 and Fig. 3.

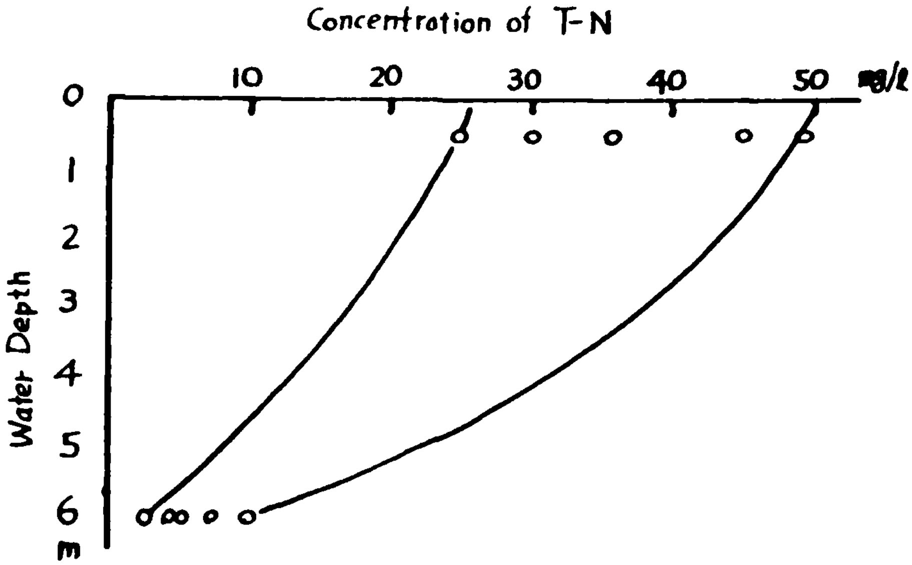


Fig. 2. *Vertical Distribution of Total Nitrogen* (T - N) in Water

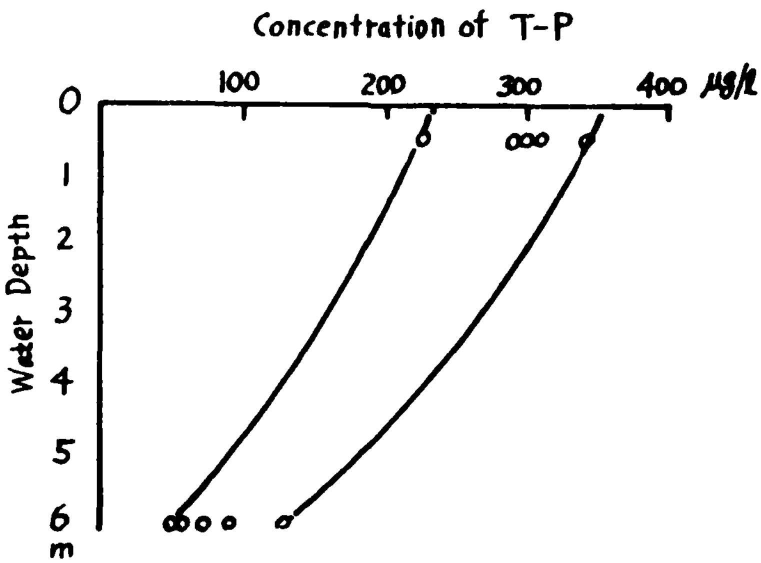


Fig. 3. Vertical Distribution of T - P in Water

If we represent such a vertical distribution by the ratios of upper concentrations to deeper ones, as indicated in Fig. 4, they have the values of 2 - 6 for T - P and 5 - 6 for T - N.

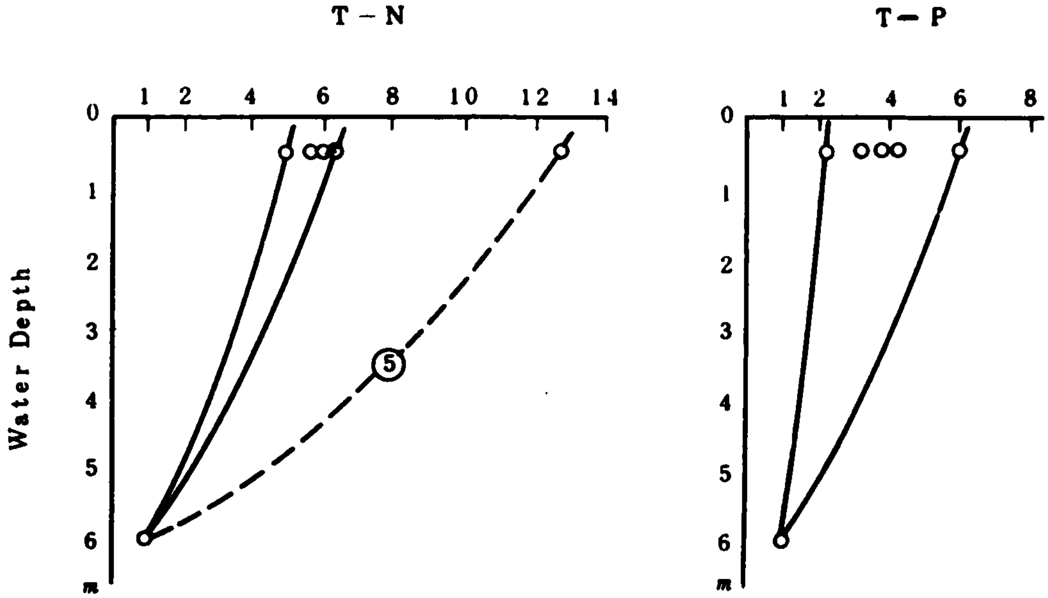


Fig. 4. Ratios of Concentrations at Surface and Bottom

The same vertical distribution of nutrient concentrations can be seen in other water areas also. Fig. 5 is an example from Tokyo Bay.

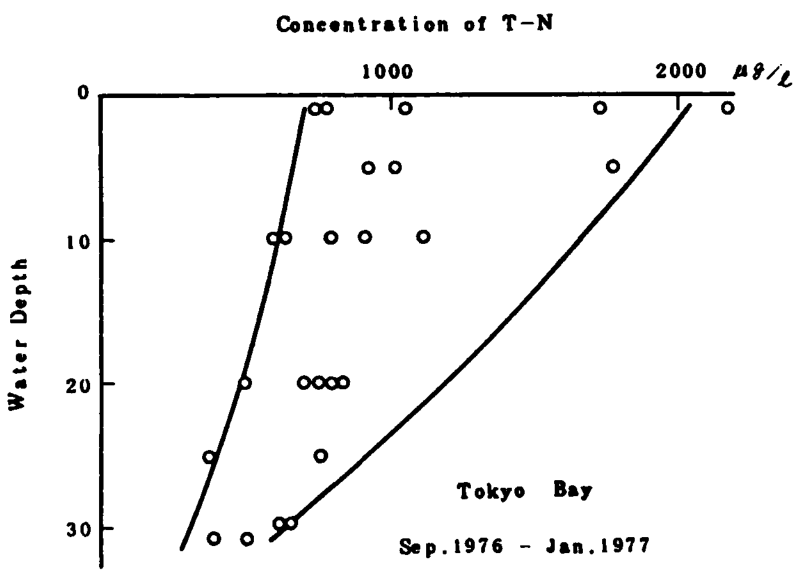
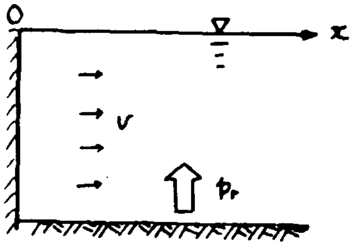


Fig. 5. Vertical Profiles of Nutrients Concentrations in Tokyo Bay

2. Diffusion of Released Materials



The behavior of released materials from sediment is represented by the following equation

$$\frac{\partial c}{\partial t} + V_x \frac{\partial c}{\partial x} = D_x \frac{\partial^2 c}{\partial x^2} + D_z \frac{\partial^2 c}{\partial z^2} \tag{1}$$

where:

c = concentration of released material

V_x = mean tide velocity of water area

D_x = diffusion coefficient in the horizontal direction

D_z = diffusion coefficient in the vertical direction

If the water flow is steady, Eq (1) becomes:

$$V_x \frac{\partial c}{\partial x} = D_x \frac{\partial^2 c}{\partial x^2} + D_z \frac{\partial^2 c}{\partial z^2} \tag{2}$$

To solve Eq (2), we transform the coordinate axes as follows

$$\left.\begin{aligned} \phi(\xi,\zeta) &= c(x,z)e^{-(V_x/2D_x)x} \\ \xi &= \frac{V_x}{2D_x}\, x \\ \zeta &= \frac{V_x}{2D_z}\sqrt{\frac{D_z}{D_x}}\, z \end{aligned}\right\} \tag{3}$$

From the transformation we get

$$\frac{\partial^2 \phi}{\partial \xi^2} + \frac{\partial^2 \phi}{\partial \zeta^2} - \phi = 0 \tag{4}$$

The general solution of Eq (4) is represented by

$$\phi = (A \cos \lambda\zeta + B \sin \lambda\zeta)\left(C \cos h \sqrt{\lambda^2 + 1} \cdot \xi + D \sin h \sqrt{\lambda^2 + 1} \cdot \xi\right)$$

The boundary conditions are defined as follows

i) $x = 0$ $\quad -V_x C + D_x \dfrac{\partial c}{\partial x} = 0$

$\xi = 0$ $\quad \dfrac{\partial \phi}{\partial \xi} - \phi = 0$

$$D \sqrt{\lambda^2 + 1} = C$$

ii) $z = 0$ $\quad D_z \dfrac{\partial c}{\partial z} = 0$

$\zeta = 0$ $\quad \dfrac{\partial \phi}{\partial \zeta} = 0$

$$B = 0$$

iii) $z = H$ $\quad C = C_B$

C_B denotes the concentration at sea bottom.

$\zeta = h$ $\quad C_B = |\phi e^{\xi}|_{\zeta = h}$

$$\sqrt{\lambda^2 + 1} \cos h \sqrt{\lambda^2 + 1} \cdot \xi + \sin h \sqrt{\lambda^2 + 1} \cdot \xi = \frac{C_B e^{-\xi}}{AD \cos \lambda h}$$

Hence we get

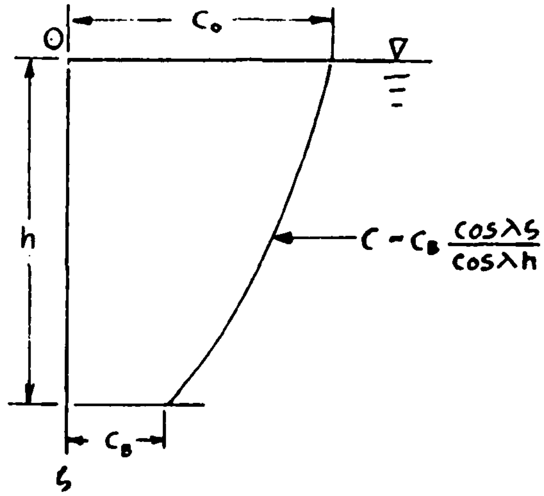
$$\phi = AD \cos \lambda\zeta\left(\sqrt{\lambda^2 + 1} \cos h \sqrt{\lambda^2 + 1} \cdot \xi + \sin h \sqrt{\lambda^2 + 1} \cdot \xi\right)$$

$$= AD \cos \lambda\zeta x \frac{C_B e^{-\xi}}{AD \cos \lambda h}$$

$$= C_B \frac{e^{-\xi} \cos \lambda\zeta}{\cos \lambda h}$$

Therefore, we obtain finally

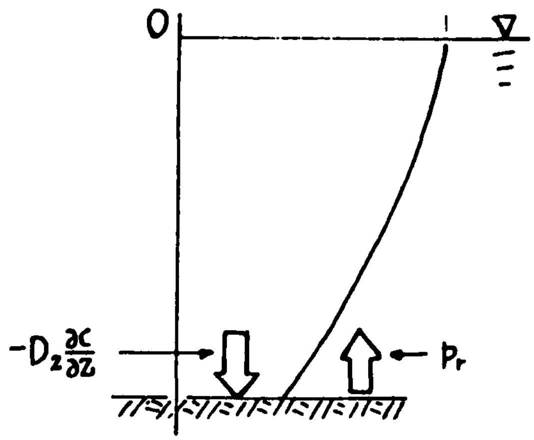
$$C = \phi e^{\xi} = C_B \frac{\cos \lambda\zeta}{\cos \lambda h} \tag{5}$$



This equation represents a vertical distribution of released materials. Therefore, the ratio of upper concentrations and deeper ones becomes

$$\frac{C_O}{C_B} = \frac{1}{\cos \lambda h}$$

3. Boundary Conditions of Sediment Surface



Since the vertical distribution of released materials is now known, the quantities which diffuse downward and reach the sediment surface can be obtained $-D_z(\partial c/\partial z)$ per unit area and unit time. Besides the released quantities per unit area and unit time, release rates, P_r, from inside the

sediment are also given. As both quantities should be in equilibrium, at the bottom we get

$$-D_z \frac{\partial c}{\partial z} - P_r = 0 \tag{6}$$

$$\therefore \frac{\partial c}{\partial z} = -\frac{P_r}{D_z}$$

Hence

$$\frac{\partial c}{\partial z} = \left|\frac{\partial c}{\partial \zeta}\right|_{\zeta=h} \frac{\partial \xi}{\partial z}$$

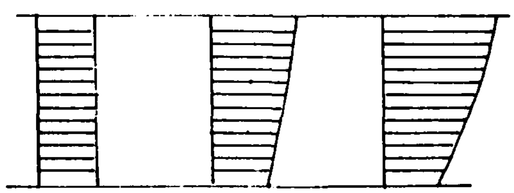
$$= -\frac{\lambda \sin \lambda h}{\cos \lambda h} \frac{V_x C_B}{2D_z} \sqrt{\frac{D_z}{D_x}} = -\frac{P_r}{D_z}$$

Finally

$$P_r = \lambda \tan \lambda h \frac{C_B V_x}{2} \sqrt{\frac{D_z}{D_x}} \tag{7}$$

This is the equation of release rates, which can be induced from the vertical profiles.

From these mathematical considerations, we can say that the vertical profiles of water concentrations are very important for release mechanics and also represent the release rates.



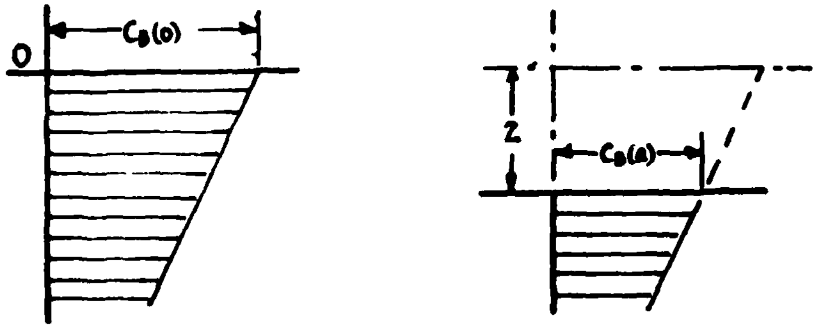
$p_r = 0$ small p_r large p_r

If the profile is a vertical line, no release occurs. That is $P_r = 0$. In the case that the concentrations at upper layers are larger than the ones at bottom layers, release from sediment takes place. The more skewed the profile curve, the more the released quantities, that is, a larger P_r.

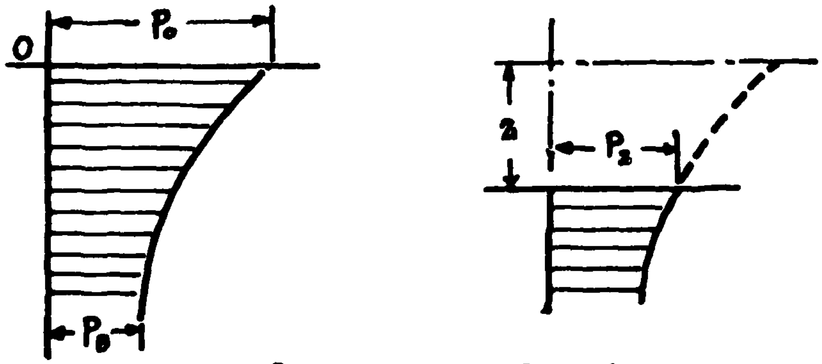
4. Prediction of Concentrations at Bottom

When we predict the water quality improvement from sediment removal, we

are confronted with the problem of how to estimate the water concentrations at the bottom. In this case, we assume that the ratios of released materials concentrations before and after dredging are equal to those of the surface concentrations of pollutants contained in sediment because the concentrations



Concentration in Pore Water



Concentration in Solid Phase

in pore water are in proportion to those in sediment. Then we get

$$\frac{C_B(a)}{C_B(o)} = \frac{P_z}{P_o} = \frac{P_B + \frac{(Z_B - Z)^2}{2f_p}}{P_o} \tag{8}$$

where

P_o = concentration at sediment surface

P_z = concentration at sediment surface after removal of its depth Z

f_p = figure index of parabolic distribution

Z_B = sediment depth at which contents in sediment reveal their own background values

Z = removed sediment depth

P_B = concentration at bottom of sediment

In this case for T - P , the following data are given

P_o = 2100 mg/kg

P_B = 1500 mg/kg

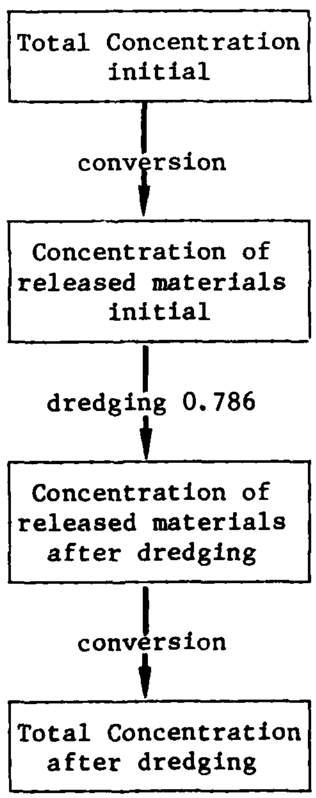
$$f_p = \frac{Z_B^2}{2(P_o - P_B)} = \frac{100^2}{2 \times 600} = 8.33\ \mathrm{cm^2 mg^{-1} kg}$$

Z_B = 100 cm

Z = 50 cm

Hence

$$\frac{C_B(a)}{C_B(o)} = \frac{1500 + \dfrac{50^2}{2 \times 8.33}}{2100} = \frac{1650}{2100} = 0.786$$



Here we show the predicted and actual values averaged for the 5 points.

	Predicted	Actual	
T - P	124	173	μg/l
T - N	7322	2954	μg/l

It may be reasonable to say that they are in fairly good agreement, considering the uneven conditions at the site.

5. Effects of Sediment Removal upon Water Quality

In order to restore the seawater at Hachinohe Harbour, a total of 194,360 m^3 of sediment was dredged during the period Nov. 1978 to Sep. 1980. To examine the effects of sediment removal, samples for water quality analysis were taken before and after dredging, Sep. 11, 1979, and Nov. 24, 1980. As mentioned before, in order to check the effects of dredging, it is best to see the changes in the vertical distribution of water quality. This is summarized in Fig. 6 and Fig. 7. These figures indicate splendidly the outstanding effects of sediment removal.

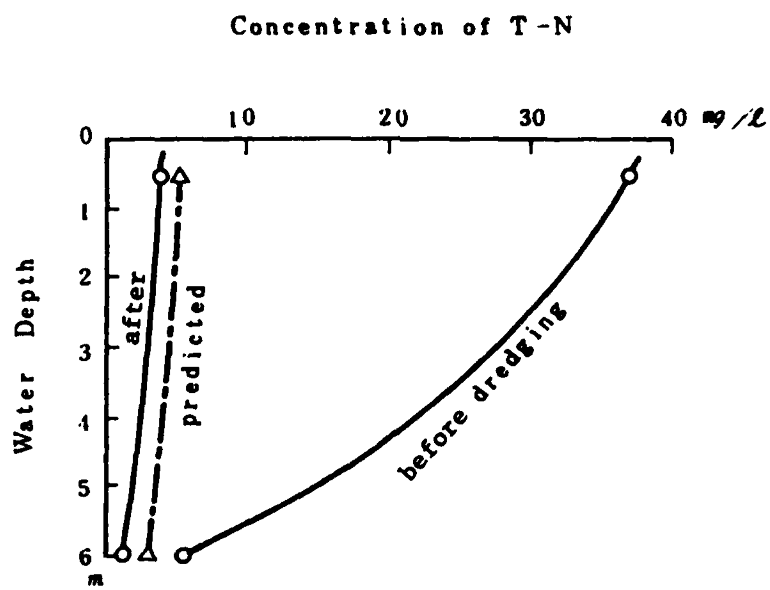


Fig. 6. Vertical Profiles of T - N before and after Dredging

When we apply the vertical profile theory to the analysis of measured values, we need to convert the total concentrations into the concentrations of released materials.

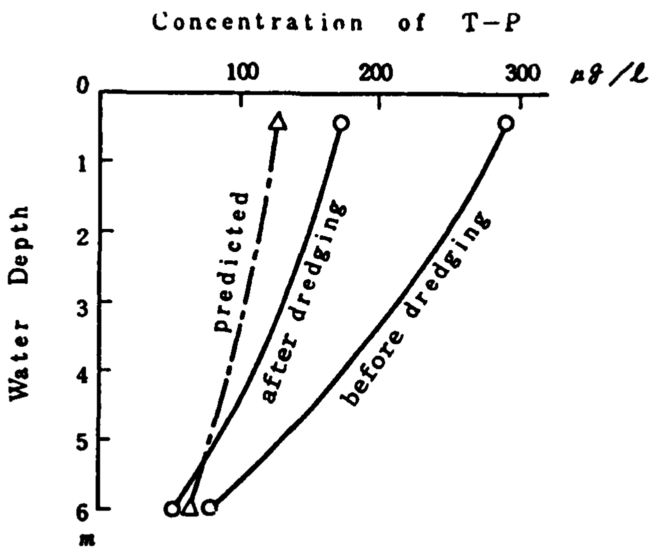


Fig. 7. Vertical Distribution of T - P in Water before and after Dredging

The total concentrations include the background (value) of seawater inflowing materials, mixed river water, and released materials. The conversion from the total concentrations to the released ones is shown in Table 1.

Table - 1

	Before dredging		After dredging	
	Total concentration measured	Converted concentration modified	Total concentration measured	Converted concentration modified
T - P	$\frac{9.48}{2.62} = 6.11$	$\frac{7.32}{2.36} = 3.10$	$\frac{5.59}{1.81} = 3.09$	$\frac{4.11}{1.55} = 2.65$
T - N	$\frac{2642}{416} = 6.35$	$\frac{2072}{374} = 5.54$	$\frac{211}{91.4} = 2.06$	$\frac{97}{49.4} = 1.96$

By putting the following data into the equation

$$h = \frac{V_x H}{2D_z} \sqrt{\frac{D_z}{D_x}}$$

$$V_x = 144 \text{ m/h} = 4 \text{ cm/s}$$

$$H = 6 \text{ m}$$

$$\sqrt{\frac{D_z}{D_x}} = 0.01 \text{ (assumed)}$$

we get

$$h = \frac{144 \times 6}{2D_z} \times 0.01 = \frac{4.32}{D_z}$$

Since the ratios of upper layer concentrations to bottom layer ones are 3.1 for T - P before dredging, and 2.65 after dredging, the values of λ are obtained as follows

$$\lambda_1 h = \cos^{-1} \frac{1}{3.10} = 1.2423$$

$$\lambda_2 h = \cos^{-1} \frac{1}{2.65} = 1.184$$

$$\lambda_1 = \frac{1.242}{h} = \frac{1.242}{\frac{4.32}{D_z}} = 0.2876D_z$$

$$\lambda_2 = \frac{1.184}{h} = \frac{1.184}{\frac{4.32}{D_z}} = 0.274D_z$$

$$\tan \lambda_1 h = 2.9343$$

$$\tan \lambda_2 h = 2.4540$$

$$P_{r_1} = \lambda_1 \tan \lambda_1 h \frac{C_{B1} V_x}{2} \sqrt{\frac{D_z}{D_x}}$$

$$= 0.2876D_z \times 2.9343 \times \frac{73.16 \times 144}{2} \times 0.01$$

$$= 44.45D_z$$

$$P_{r_2} = 0.274D_z \times 2.454 \times \frac{48.05 \times 144}{2} \times 0.01$$

$$= 23.26D_z$$

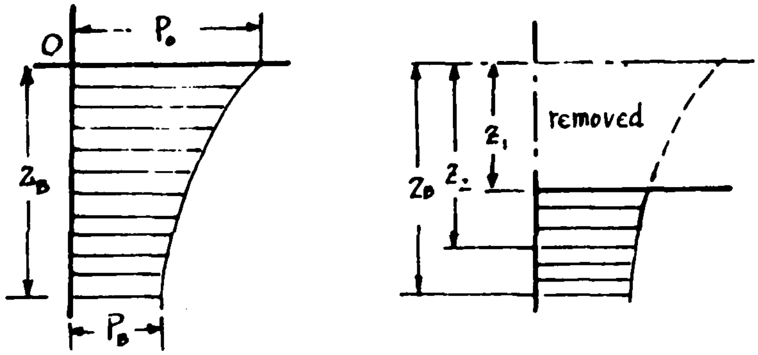


Fig. 8. Symbols for Calculation of Removed Sediment

On the other hand, we can obtain the release rates theoretically from Yoshida's theory on release mechanism as follows

$$P_{r_1} = \frac{26\xi\left[P_B Z_r + \dfrac{Z_B^3 - (Z_B - Z_r)^3}{6f_p}\right]}{(1 + e_o)\left(\dfrac{Z_r}{H} + \dfrac{\tan \lambda_1 h}{\lambda_1 h}\right)} \tag{9}$$

$$P_{r_2} = \frac{26\xi\left[P_B Z_r + \dfrac{(Z_B - Z_1)^3 - (Z_B - Z_2)^3}{6f_p}\right]}{(1 + e_o)\left(\dfrac{Z_r}{H} + \dfrac{\tan \lambda_2 h}{\lambda_2 h}\right)} \tag{10}$$

$$Z_r = Z_2 - Z_1$$

Where

P_{r_1} = release rates of T - P before dredging

P_{r_2} = release rates of T - P after dredging

ξ = partition coefficient of T - P

P_B = background value of T - P concentration in sediment

Z_B = sediment depth where N_B is revealed

Putting the next values into Eq (9) and (10)

$$P_B = 1500 \text{ mg/kg}$$

$$f_p = 8.33 \text{ cm}^2\text{mg}^{-1}\text{kg}$$

$$Z_r = 30 \text{ cm}$$

$$Z_B = 100 \text{ cm}$$

$$Z_1 = 50 \text{ cm (removed depth)}$$

$$Z_2 = 50 + 30 = 80 \text{ cm}$$

$$H = 600 \text{ cm}$$

$$\tan \lambda_1 h = 2.934$$

$$\lambda_1 h = 1.242$$

$$\tan \lambda_2 h = 2.454$$

$$\lambda_2 h = 1.1839$$

$$P_{r_1} = \frac{26\xi\left(1500 \times 30 + \dfrac{100^3 - 70^3}{6 \times 8.33}\right)}{(1 + 5)\left(\dfrac{30}{600} + \dfrac{2.934}{1.242}\right)} = 104{,}462\xi$$

$$P_{r_2} = \frac{26\xi\left(1500 \times 30 + \dfrac{50^3 - 20^3}{6 \times 8.33}\right)}{(1 + 5)\left(\dfrac{30}{600} + \dfrac{2.454}{1.184}\right)} = 96{,}639\xi$$

For the values of partition coefficients we have obtained the laboratory test results as indicated in Fig. 9.

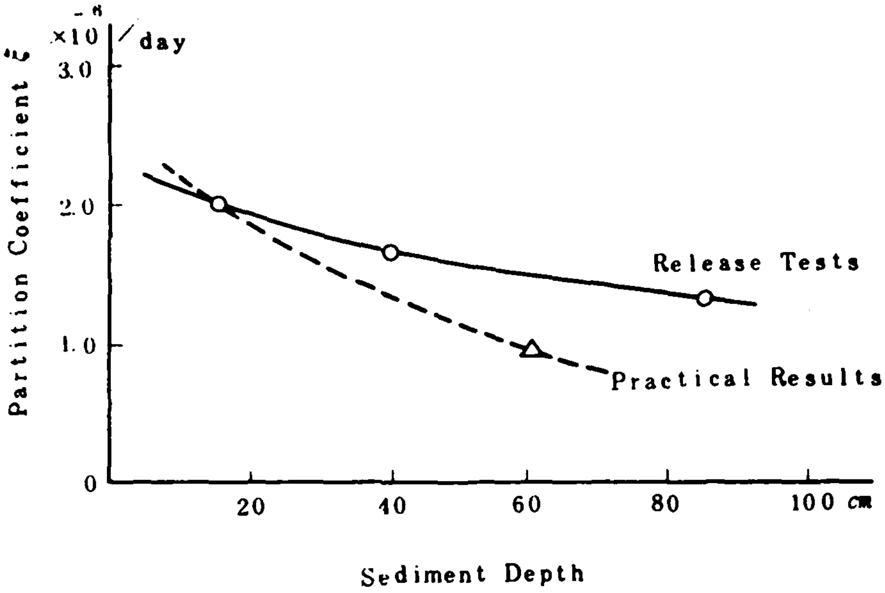


Fig. 9. Relationship Between ξ and Sediment Depth for T - P

Now assuming $\xi = 1.8 \times 10^{-6}$/day for a removed depth of 50 cm, we get

$$P_{r_1} = 104{,}462\xi = 104{,}462 \times 1.8 \times 10^{-6} = 0.188 \text{ mg/m}^2\text{/d}$$

$$D_z = \frac{P_{r1}}{44.45} = \frac{0.188}{44.45} = 0.0042 \text{ m}^2\text{/h}$$

$$P_{r_2} = 23.66D_z = 23.26 \times 0.0042 = 0.098 \text{ mg/m}^2\text{/d}$$

$$\xi_2 = \frac{P_{r_2}}{96{,}639} = \frac{0.098}{96{,}639} = 1.01 \times 10^{-6}\text{/d}$$

In the same way we get the released rates and diffusion coefficients for T - N:

$$n_{r_1} = 6606.4D_z$$

$$n_{r_2} = 201.2D_z$$

$$n_{r_1} = 111084\xi_1$$

$$n_{r_2} = 158252\xi_2$$

Assuming $\xi_1 = 1.6 \times 10^{-4}$/day

$$\eta_{r_1} = 111084\xi_1 = 111084 \times 1.6 \times 10^{-4} = 17.77 \text{ mg/m}^2\text{/d}$$

$$D_z = \frac{17.77}{6606.4} = 0.0027 \text{ m}^2\text{/h}$$

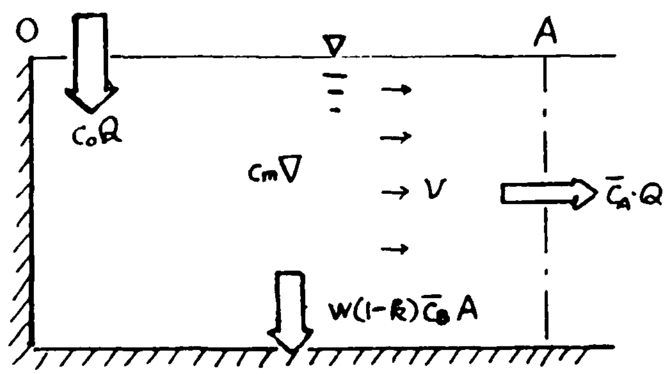
$$\eta_{r_2} = 201.2D_z = 201.2 \times 0.0027 = 0.54 \text{ mg/m}^2\text{/d}$$

$$\xi_2 = \frac{0.54}{158{,}252} = 3.4 \times 10^{-6}\text{/day}$$

As shown above, the partition coefficient ξ diminishes remarkably after dredging. In Fig. 10 the laboratory test results and the observed values of this time are plotted. From the above numerical examples, we are convinced that the vertical profile theory is reasonable and effective for practical uses.

The special feature of this theory is to predict simply the release rates of the concerned water area without release tests in the laboratory, as long as the partition coefficient ξ is known.

6. Effects of Inflowing Pollutants upon Water Quality



The movement of inflowing pollutant particles is represented as follows

$$V \frac{\partial c}{\partial x} + W \frac{\partial c}{\partial z} = D_x \frac{\partial^2 c}{\partial x^2} + D_z \frac{\partial^2 c}{\partial z^2} \tag{11}$$

Where:

V = tide velocity

W = mean setting velocity of inflowed particles

D_x = diffusion coefficient in the horizontal direction

D_z = diffusion coefficient in the vertical direction

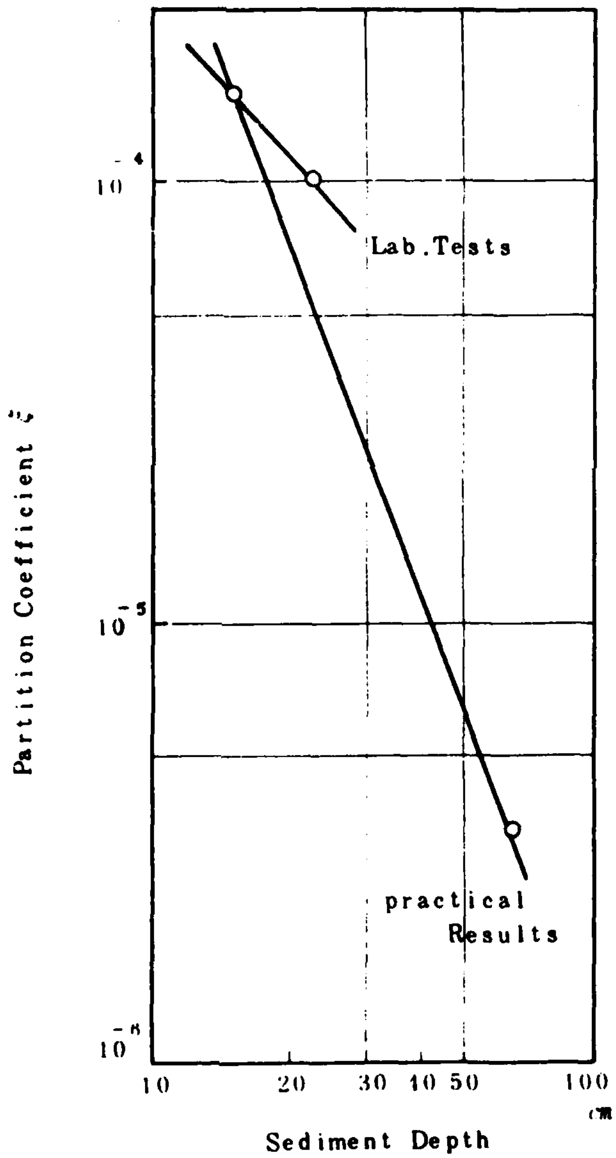


Fig. 10. Relationship Between ξ and Sediment Depth for T - N

The exact solution of Eq (11) is obtained by the necessary mathematical processes (omitted here)

$$\frac{C}{C_o} = \sum_{n=1}^{\infty} \frac{2\lambda_n^2 a\left[2b_1 a - e^{-b_1 h}(b_1 - b_2)\left(\lambda_n^2 + b_1^2\right)\right](\lambda_n \cos \lambda_n \zeta + b_1 \sin \lambda_n \zeta)\left(\sqrt{\lambda_n^2 + 1} \cos h \sqrt{\lambda_n^2 + 1} \cdot \xi + a \sin \sqrt{\lambda_n^2 + 1} \cdot \xi\right)}{\left(\lambda_n^2 + b_1^2\right)^2\left[ha^2 + (b_1 + b_2)\left(\lambda_n^2 + b_1 b_2\right)\right]\left(\sqrt{\lambda_n^2 + 1} \cos h \sqrt{\lambda_n^2 + 1} \cdot \ell + a \sin h \sqrt{\lambda_n^2 + 1} \cdot \ell\right)} \times e^{a\xi + b_1 \zeta} \qquad (12)$$

$$C_m = \frac{1}{h\ell}\int_o^{\ell}\int_o^{h} C\,d\xi\,d\zeta$$

And the mean values at the bottom and at the outlet are represented respectively:

$$\overline{C}_B = \frac{1}{\ell}\int_o^{\ell} C_B(\xi,h)\,d\xi$$

$$\overline{C}_A = \frac{1}{h}\int_o^{h} C_A(\ell,\zeta)\,d\zeta$$

If as follows:

$$C_m = \Psi_m C_o$$

$$\overline{C}_A = \Psi_A C_o$$

$$\overline{C}_B = \Psi_B C_o$$

We obtain the following equation on mass balance of pollutants:

$$C_o(1 - \Psi_A)Q = \frac{\nabla}{6} \Psi_m C_o + W(1 - K)\Psi_B C_o A \tag{13}$$

Where:

Q = quantities of influx

A = area of sea bottom

∇ = water volume of harbour

These values are all nondimensional

$$\left.\begin{aligned}
a &= \frac{V}{D_x}\sqrt{\frac{D_x}{\frac{V^2}{D_x} + \frac{W^2}{D_z}}} \\
b_1 &= \frac{W}{D_z}\sqrt{\frac{D_z}{\frac{V^2}{D_x} + \frac{W^2}{D_z}}} \\
b_2 &= \frac{W}{D_z}(1 - 2K)\sqrt{\frac{D_z}{\frac{V^2}{D_x} + \frac{W^2}{D_z}}} \\
h &= \frac{H}{2}\sqrt{\frac{\frac{V^2}{D_x} + \frac{W^2}{D_z}}{D_z}} \\
\ell &= \frac{L}{2}\sqrt{\frac{\frac{V^2}{D_x} + \frac{W^2}{D_z}}{D_x}} \\
\alpha^2 &= \lambda_n^4 + \left(b_1^2 + b_2^2\right)\lambda_n^2 + b_1^2 b_2^2
\end{aligned}\right\} \tag{14}$$

The vertical distribution of inflowing particles is obtained by Eq (12) and shows the profile which is indicated in Fig. 11. The mean concentration in the whole harbour is calculated by the following equation (Eq (13) is rewritten as follows):

$$1 - \Psi_A = \frac{\nabla}{6Q} \Psi_m + (1 - K) \frac{WA}{Q} \Psi_B$$

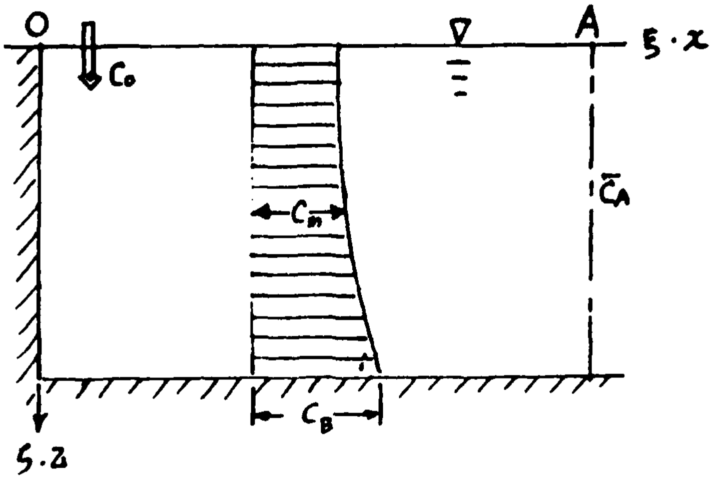


Fig. 11. Vertical Profile of Inflowing Pollutants

In this equation it is acceptable to put $\Psi_m = \Psi_B$ in practice, so we get:

$$\Psi_m = \frac{1 - \Psi A}{\frac{\nabla}{6Q} + (1 - K)\ \frac{WA}{Q}} \tag{15}$$

This represents the direction of inflowing pollutants.

For Hachinohe Harbour the value of Ψ_m becomes:

$$Q = 100{,}000\ m^3/day = 4.167\ m^3/h$$

$$A = 2{,}500 \times 150 = 375{,}000\ m^2$$

$$\nabla = 2{,}500 \times 150 \times 6 = 2{,}250{,}000\ m^3$$

$$K = 0.1$$

$$W = 0.02\ m/h$$

$$\Psi_A = 0 \quad \text{(for high tide)}$$

$$\Psi_m = \frac{1}{\frac{2{,}250{,}000}{6 \times 4{,}167} + 0.9 \times 0.02\ \frac{375{,}000}{2{,}250{,}000}}$$

$$= \frac{1}{89.99 + 0.003} = 0.011$$

That is, the influx of pollutants is diluted to one percentage of its concentration in this case.

7. Conclusions

To check the effects of sediment removal in Hachinohe Harbour, the water quality before and after dredging was measured systematically on a full scale under the auspices of the Ministry of Transport.

In such an investigation, we are lucky to have the chance to study the effects of inflowing and released pollutants upon water quality. As a result, the theory on vertical distribution profiles of released materials was developed. It is very fortunate that the theory was verified by the data of Hachinohe Harbour regarding its availability.

In the respect that this investigation helps us find a general prediction method for improving water quality by sediment removal, it is most valuable.

CONSOLIDATION AND SETTLING CHARACTERISTICS OF VERY SOFT CONTAMINATED SEDIMENTS

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ABSTRACT

With respect to the dredging and reclamation for the management of contaminated sediments, information on mechanical properties of very soft soils is normally required, although the determinations involve technical difficulties. A new method to determine the consolidation constants for very soft soils has previously been proposed. Using this method and sedimentation test methods, the consolidation and settling characteristics of contaminated sediments taken from several harbors in Japan were investigated.

The proposed method is briefly described herein. Its validity is verified by analyzing the self-weight consolidation phenomena of a model fill composed of contaminated sediments. Test results on other sediments are also presented and comparatively examined.

INTRODUCTION

In recent years, the management of marine contaminated bottom sediments has received considerable attention from the point of view of the cleanup of the surrounding environment. The contaminated sediments to be managed are classified into such categories as toxic sediments, organic sediments, oily sediments, and their mixtures. Management of these contaminated sediments is fundamentally implemented by dredging and reclamation. The contaminated sediments removed by dredging must be finally disposed into a specific reclamation site. Various problems must be considered such as preparation of a suitable reclamation site, prevention of secondary pollution, and utilization of the reclaimed site. In such cases, it is very difficult to locate a sufficiently large reclamation site for the huge amount of dredged soils. Therefore, the minimum space needed for the confinement of dredged material must be estimated accurately. There are many technical difficulties

involved with this estimation. One of the most important problems is estimating the settlement in the reclamation site, which is usually formed with very soft materials and is in an underconsolidated state. Since Terzaghi's consolidation theory is not applicable in such a case, it is necessary to use the consolidation theory proposed by Mikasa (1963) or Monte and Krizek (1976). A new laboratory testing procedure to determine the consolidation constants accurately has been previously proposed by the authors (1980) as an alternative to the conventional oedometer test method. In the present report, the laboratory testing procedure proposed for very soft soils is briefly described and its validity is verified by analyzing the self-weight consolidation phenomena of a model fill composed of contaminated sediments. Test results on very soft soils including contaminated sediments taken from various harbors in Japan are presented to examine the consolidation and settling characteristics of such materials on a comparative basis.

EVALUATION METHOD OF CONSOLIDATION CHARACTERISTICS OF VERY SOFT SOILS

Principle of Constant Rate of Strain Consolidation with Consideration of Large Strain Effects

The conventional oedometer test is not applicable to very soft soils due to limitations both in theory and in testing techniques. As an alternative, the authors have previously proposed the test method based on the constant rate of strain consolidation and further proposed a new interpretation of the CRS-test results (Umehara and Zen, 1980). The theoretical background will be briefly reviewed below.

Mikasa (1963) has proposed the extended consolidation theory including the effect of large strain and self-weight of the soil. In the case of laboratory consolidation tests on small specimens, the stresses arising from the self-weight of the specimen may be considered negligible compared with those applied. If the coefficient of consolidation, C_V, is assumed to be independent of depth at any time, the basic equation of consolidation is

$$\frac{\partial\zeta}{\partial t}=C_V\zeta^2\frac{\partial^2\zeta}{\partial z_o{}^2} \qquad (1)$$

in which C_V is the coefficient of consolidation; t is the time; z_o is the original coordinate; $\zeta=f_o/f$ is the consolidation ratio; f is the volume ratio

at time, t; f_o is the initial volume ratio. The consolidation ratio, ζ, can be related to the axial strain, $\bar{\varepsilon}$, by the relation $\zeta=1/(1-\bar{\varepsilon})$.

In the constant rate of strain consolidation test, the sample is loaded at the constant rate of deformation, R. That is, at time, t, the sample of initial height, H_o, is deformed vertically by $\Delta H_o=Rt$ at the surface of the specimen; hence, the average vertical strain, $\Delta H_o/H_o$, is

$$\frac{\Delta H_o}{H_o} = \frac{Rt}{H_o} = T' \tag{2}$$

in which T' is the dimensionless time.

Since Eq.(1) is analytically unsolvable, Eq.(1) is replaced by the finite difference equation:

$$\zeta(z_o,t+\Delta t)-\zeta(z_o,t)=\frac{C_v\Delta t}{\Delta z_o^2}\bar{\zeta}^2\{\zeta(z_o+\Delta z_o,t)-2\zeta(z_o,t)+\zeta(z_o-\Delta z_o,t)\} \tag{3}$$

Considering the following nondimensional variables:

$$\begin{aligned} Z_o&=\frac{z_o}{H_o} \\ \Delta Z_o&=\frac{1}{n} \\ \frac{C_v\Delta t}{\Delta z_o^2}&=n^2\left(\frac{C_v}{RH_o}\right)\frac{R\Delta t}{H_o}=n^2\left(\frac{C_v}{RH_o}\right)\Delta T' \end{aligned} \tag{4}$$

Eq.(3) can be expressed by the form:

$$\zeta(Z_o,T'+\Delta T')-\zeta(Z_o,T')=n^2\left(\frac{C_v}{RH_o}\right)\Delta T'\cdot\bar{\zeta}^2\{\zeta(Z_o+\Delta Z_o,T')-2\zeta(Z_o,T')+\zeta(Z_o-\Delta Z_o,T')\} \tag{5}$$

in which $\bar{\zeta}$ is a certain value between $\zeta(Z_o,T')$ and $\zeta(Z_o,T'+\Delta T')$.

Assuming that the clay specimen has a freely drained layer at the top surface and an impervious boundary at the bottom surface, the initial and boundary conditions are given by

$$\zeta(Z_o,0)=1 \tag{6}$$

$$\zeta(0,T')=\phi(T') \tag{7}$$

$$\left(\frac{\partial\zeta(Z_o,T')}{\partial Z_o}\right)_{Z_o=1}=0 \tag{8}$$

In addition, the following deformation condition under the constant rate of

strain condition must be satisfied at any **nondimensional time**, T':

$$\int_0^1 \bar{\varepsilon}(Z_O,T')dZ_O=\int_0^1\left(1-\frac{1}{\zeta(Z_O,T')}\right)dZ_O=\frac{\Delta H_O}{H_O} \qquad (9)$$

Since the $\phi(T')$ at the top boundary in Eq.(7) is given in an implicit form, it is given as a first approximation so that for $T'=\Delta T'$:

$$\phi(T')=\frac{1}{1-\bar{\varepsilon}(0,\Delta T')} \fallingdotseq \frac{1}{1-\Delta T'} \qquad (10)$$

The value of $\phi(T')$ for the next step of numerical calculation must be determined so that the calculated displacement should be consistent with the deformation condition of Eq.(9).

The boundary **condition at the bottom of the specimen is introduced in** the numerical calculation by establishing the imaginary point with the space mesh equal to 1/n below the impervious base, then assuming the same value of ζ as that for the space point on the impervious base.

The solution of Eq.(5), **for the consolidation ratio**, ζ, satisfying the initial condition of Eq.(6), boundary conditions of Eq.(7) and Eq.(8), and the deformation condition of Eq.(9), can be obtained by the finite difference method. The solution is given as the function of two variables, that is, nondimensional space, Z_O, and nondimensional time, T', for a given nondimensional parameter, C_v/RH_O. Fig.1 shows a typical example of the variations of strain distribution for C_v/RH_O = 1.0, where $\bar{\varepsilon}$ indicates the compression strain and has such a relationship with either consolidation ratio, ζ, or volume ratio, f, as given by

$$\bar{\varepsilon}=1-\frac{1}{\zeta}=1-\frac{f}{f_O} \qquad (11)$$

Three kinds of diagrams are constructed on the basis of such computation results for various values of C_V/RH_O as shown in Fig.1. These diagrams are those indicating: the variations of consolidation ratio at the top, $\zeta_T=f_O/f_T$, with the average strain, $\Delta H_O/H_O$; the variations of consolidation ratio at the bottom, $\zeta_B=f_O/f_B$, with the average strain, $\Delta H_O/H_O$; and the variations of the ratio of

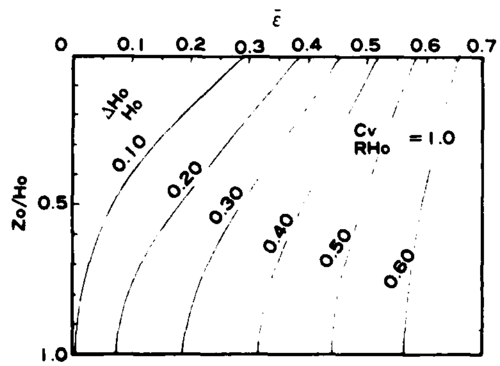

Fig.1 Strain distribution within the specimen for variations of average strain (C_V/RH_O=1.0)

bottom strain to top strain, F, for various values of C_v/RH_o. The ratio, F, is given by

$$F=\left(\frac{f_o}{f_B}-1\right)\cdot\frac{f_o}{f_T}\Big/\left\{\left(\frac{f_o}{f_T}-1\right)\cdot\frac{f_o}{f_B}\right\} \tag{12}$$

where f_T and f_B indicate the volume ratio at the top and at the bottom of the specimen, respectively. Three kinds of diagrams described above are shown in Fig.6, Fig.7, and Fig.8 together with an example of their use, which is explained later.

Determination of C_v and f-logσ' Relation

If the nonlinear stress-strain relation given by

$$f=f_o-C_c\log\left(\frac{\sigma'}{\sigma_o'}\right) \tag{13}$$

holds, then the value of F given by Eq.(12) can be represented by

$$F=\frac{\log(\sigma-u_h)-\log\sigma_o'}{\log\sigma-\log\sigma_o'} \tag{14}$$

where σ' is the effective stress; σ_o' is the effective stress at the initial state; C_c is the compression index; f_o is the volume ratio at the initial state; σ is the total stress; and u_h is the excess pore water pressure.

Once the effective stresses both at the top and at the bottom of the specimen and the average strain at any time, t, are known from the CRS tests, the coefficient of consolidation, C_v, and the volume ratio versus log of effective stress relationship, f-logσ', can be determined using Eq.(14) and Fig.6, Fig.7, and Fig.8 as explained later with an example.

CONSOLIDATION AND SETTLING TESTS ON VERY SOFT CONTAMINATED SEDIMENTS

Samples Tested

The samples employed in the present experiments were taken from various harbor areas in Japan as shown in Fig.2. The physical properties of the samples are summarized in Table 1.

Minamata Bay muds contaminated with mercury were investigated to obtain information on the management by reclamation. Fushiki Toyama Port muds were investigated to examine the current determination method of the minimum space for a reclamation site. Osaka Bay muds contain a large amount of oily substance and Nagoya Port muds contain a large amount of organic matter. Honmoku clay is a

Table 1 Physical properties of samples

Sample	G_s	w_L (%)	w_P (%)	I_P	Gradation(%) Sand	Silt	Clay	Ignition Loss(%)
Honmoku Clay	2.71	96.7	41.5	55.2	8.7	40.1	51.2	11.0
Tokyo Bay Muds	2.65	125.3	38.6	86.7	22.1	53.4	24.5	13.8
Yokohama Port Muds	2.71	73.4	39.2	34.2	24.1	40.9	35.0	10.6
Nagoya Port Muds	2.57	164.0	45.9	118.1	6.3	44.2	49.5	24.8
Osaka Bay Muds	2.59	102.8	45.8	57.0	20.0	43.0	37.0	18.1
Fushiki Toyama Port Muds, B-south	2.62	59.4	35.0	24.4	15.4	49.6	35.0	7.5
Fushiki Toyama Port Muds, B-north	2.63	97.6	48.2	49.4	2.3	53.7	44.0	12.7
Minamata Bay Muds	2.71	96.0	38.5	57.5	10.1	45.9	44.0	21.5

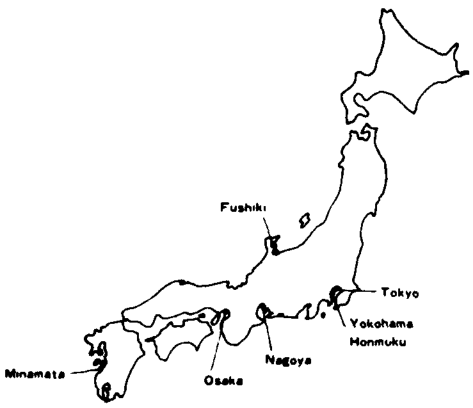

Fig.2 Sampling sites

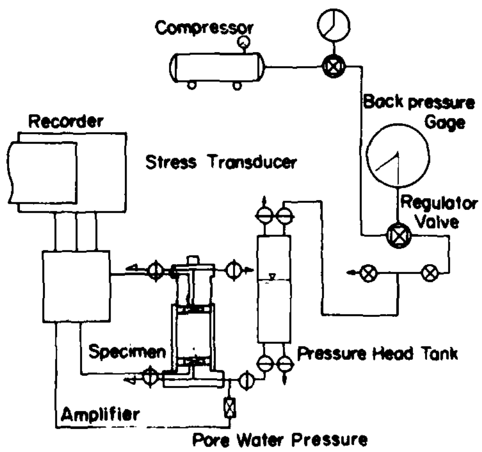

Fig.3 Set up of the constant rate of strain consolidation test apparatus

typical alluvial clay taken from a deeper location, while Tokyo Bay muds and Yokohama Port muds are near-surface bottom sediments.

Apparatuses

Constant Rate of Strain Consolidation Test Apparatus

A schematic drawing of the apparatus for constant rate of strain consolidation tests is shown in Fig.3. The consolidometer consists of the loading apparatus, the consolidation cell, and loading piston. The loading apparatus has such a mechanism that the specimen can be subjected to loading at a constant pressure or at a constant velocity. The velocity can be varied at 30 steps between 4.4×10^{-4}mm/min and 5.0mm/min. Further details on the apparatus are described elsewhere (Umehara and Zen, 1980).

Settling Test Apparatus

The settling test apparatus is a transparent acrylic cylinder having an inner tube consisting of sliced thin rings made of acryl. The outer tube is 68mm in inside diameter by 360mm high and a ring composing the inner tube is 62mm in inside diameter by 10mm high.

Experimental Apparatus for Self-Weight Consolidation

An iron box having the dimensions of 150cm long, 100cm wide, and 100cm deep was used to observe the self-weight consolidation. A transparent acrylic window is installed along the vertical line of one side wall in order to observe the behavior inside the box.

The settlement device consists of the brass rod with a square plate at the top and an acrylic outer tube for protection. The excess pore water pressure is picked up by a brass tip with porous stone and measured by a hydraulic manometer through the flexible vinyl tube.

Experimental Procedures

Constant Rate of Strain Consolidation Tests

Each sample used was completely remolded in a mixer, screened through a 0.074mm sieve and finally mixed into a slurry with a high water content. The slurry was placed under a vacuum and periodically agitated to remove entrapped air. It was then poured into a consolidation ring 30 to 50mm thick and allowed to undergo preloading to provide a test specimen 20 to 40mm high. The purpose of preloading is to specify the initial state. During preloading under a constant pressure, the stress at the bottom of the specimen was measured by a stress transducer. The effective load

will decrease because of possible friction during a constant load type of preloading, especially at the initial stage of preloading. An additional small load was applied to keep constant the effective load indicated by the stress monitored at the bottom of the specimen.

The constant rate of strain consolidation test was conducted by inducing a constant rate of deformation of the base plate with the axial load press. Throughout the test, the axial deformation, the axial stresses both at the top and at the bottom of the specimen, and the pore water pressure at the bottom of the specimen were measured. Testing conditions are summarized in Table 2.

Table 2 Testing conditions for constant rate of strain consolidation tests

Sample • Number		Before Preloading	Before Constant Rate of Strain Consolidation Test			
		Initial Water Content, w_i(%)	Initial Height, H_o(cm)	Initial Volume Ratio, f_o	Initial Stress, σ_o' (kgf/cm^2)	Strain Rate, R (cm/min)
Honmoku	H-1*	230	1.391	4.013	0.077	3.07×10^{-3}
	H-2*	230	1.963	3.958	0.103	3.07×10^{-3}
	H-3*	230	2.518	4.950	0.014	3.07×10^{-3}
	H-6	230	2.370	5.205	0.008	2.748×10^{-3}
	H-8	206	2.155	4.650	0.025	2.726×10^{-3}
Tokyo	T-1	231	1.505	4.295	0.050	2.700×10^{-3}
	T-2	232	1.555	4.291	0.054	2.717×10^{-3}
Yokohama	Y-1	219	1.425	3.130	0.019	2.713×10^{-3}
	Y-2	108	1.655	3.033	0.034	2.722×10^{-3}
Nagoya	N-1	461	2.105	11.216	0.013	2.733×10^{-3}
	N-2	458	1.575	9.830	0.010	2.729×10^{-3}
Osaka	O-1	338	1.470	6.257	0.044	2.713×10^{-3}
	O-2	320	1.430	6.604	0.027	2.723×10^{-3}
Fushiki Toyama	BS-1	128	1.905	3.132	0.034	2.703×10^{-3}
	BS-2	121	2.005	3.037	0.059	2.739×10^{-3}
	BN-1	193	1.640	4.295	0.044	2.717×10^{-3}
	BN-2	191	1.870	4.430	0.031	2.738×10^{-3}
Minamata	J-2	211	4.074	4.885	0.031	5.456×10^{-3}
	J-3*	213	3.389	4.501	0.043	5.446×10^{-3}

Note: with * : stress transducer with the max. capacity of 10kgf/cm^2 and pore pres. transducer with the max. capacity of 5.0kgf/cm^2 were used

without * : stress and pore pres. transducers with the max. capacity of 0.5kgf/cm^2 were used

Table 3 Testing conditions for settling tests

Sample	Initial water content w_0(%)	Initial height H_0(cm)	Initial Volume Ratio f_0
Honmoku Clay	287 483 800 938 1712	35.7 35.8 34.8 34.7 34.9	9.118 19.419 39.603 50.796 79.556
Tokyo Bay Muds	266 266 397 397 640 640	36.1 33.8 38.5 35.2 35.9 33.8	8.574 8.477 12.689 12.577 21.641 21.290
Yokohama Port Muds	199 199 235 235 342 342	35.4 33.0 35.8 32.8 34.8 36.5	6.773 6.862 8.024 8.023 11.423 11.623
Nagoya Port Muds	494 494 727 727 1020 1004	34.3 32.8 34.9 33.9 35.8 33.9	16.367 16.234 27.656 25.127 39.290 39.247
Osaka Bay Muds	308 308 436 556 556	34.0 35.9 34.9 34.9 33.9	10.119 10.271 14.719 19.191 19.276
Fushiki Toyama Port Muds (B-site)	124 124 191 191	34.9 33.9 33.0 38.5	4.389 4.389 6.399 6.351
Minamata Bay Muds (J-site)	382 382 382 400	35.0 35.0 35.9 79.1	12.863 12.783 12.899 13.043

Settling Tests

Three to four kinds of slurry with 200 to 1000% water content were prepared by using each sample shown in Table 1. Each slurry was poured into the inner tube of the double tube type cylinder. After the cylinder was sufficiently shaken as required in mechanical analysis, each settling test was begun on a respective specimen. During the test, the settlement of the interface between the dispersion and clear water was recorded at a proper time interval. The testing conditions used for the present series of settling tests are summarized in Table 3.

After the settling test was completed, each sliced ring within the cylinder was pushed up one after another as shown in Fig.4. By measuring the water content of the soil in each ring, the water content distribution was obtained for each test in the same manner as used by Yano et al. (1977).

Experiment on Self-Weight Consolidation

The slurry with 200 to 230% water content was made by remolding Osaka Bay muds and was poured into the iron box described previously to make a model fill. The initial water content of each layer was measured beforehand. It took about two hours to complete the model fill which was 80cm high. The self-weight consolidation of the model fill was started under the single drainage condition with the impermeable base and the permeable boundary at the top. Throughout the self-weight consolidation process, the settlements and excess pore water pressures at several points in the model fill were measured by the settlement devices and manometers, respectively.

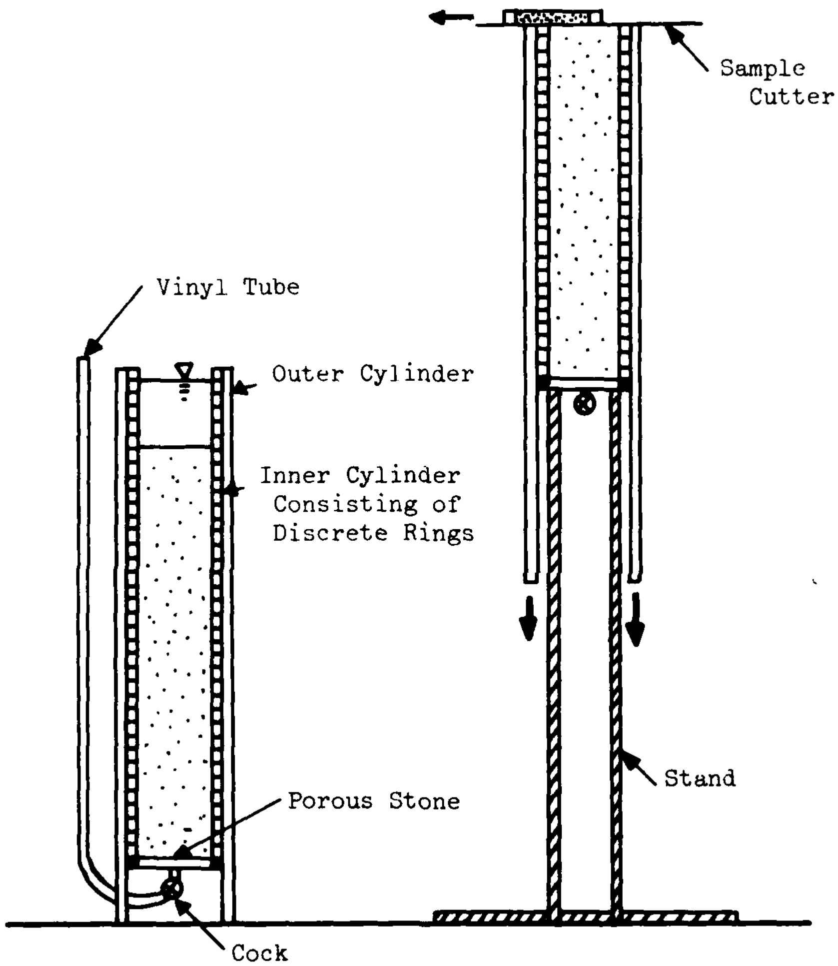

Fig.4 Schematic drawing of settling test apparatus

PRESENTATION AND DISCUSSION OF TEST RESULTS

Interpretation of CRS Test Results

A series of constant rate of strain consolidation tests was conducted on each specimen whose initial state was specified by preloading under a constant load. While the displacement was increased in proportion to time during loading, the stress and pore water pressure at the bottom of the specimen were measured by each transducer. For recording them, a digital volt meter was used. Fig.5 shows a typical example of the test data.

On the basis of such data as shown in Fig.5, the coefficient of consolidation, C_v, and the volume ratio versus log of effective stress, f-logσ', relationship can be determined in the following procedure:

Step 1: Determination of σ_o' in the initial state; σ_o' is determined by measuring the stress just after preloading

Step 2: Determination of the stress, pore water pressure, and displacement for each time interval

Step 3: Computation of both effective stress at the top and at the bottom of the specimen and computation of F values

Step 4: Computation of average strain for each time, $\Delta H_o/H_o$

Step 5: Determination of C_v. The values of F and $\Delta H_o/H_o$ are used to find C_v/RH_o corresponding to $\Delta H_o/H_o$ at time, t, as shown in Fig.8; hence C_v can be determined

Step 6: Computation of both f_T and f_B. The value of C_v/RH_o obtained above can be used to find the volume ratio, f_T and f_B, as shown in Fig.6 and Fig.7, respectively

Step 7: Determination of f-logσ'. The f-logσ' relationship can be established by plotting f_T or f_B against each corresponding effective stress

Step 8: Determination of σ_{av}'. The average effective stress, σ_{av}', can be determined by finding the stress corresponding to the average volume ratio $f_{av}=f_o(1-\Delta H_o/H_o)$ on the f-logσ' relationship established

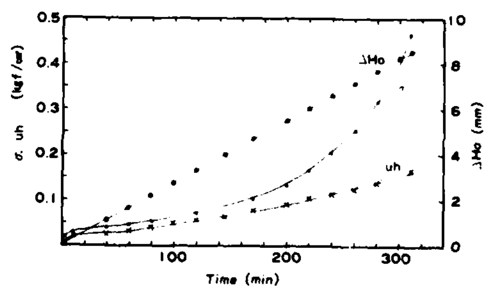

Fig.5 A typical record of constant rate of strain consolidation tests

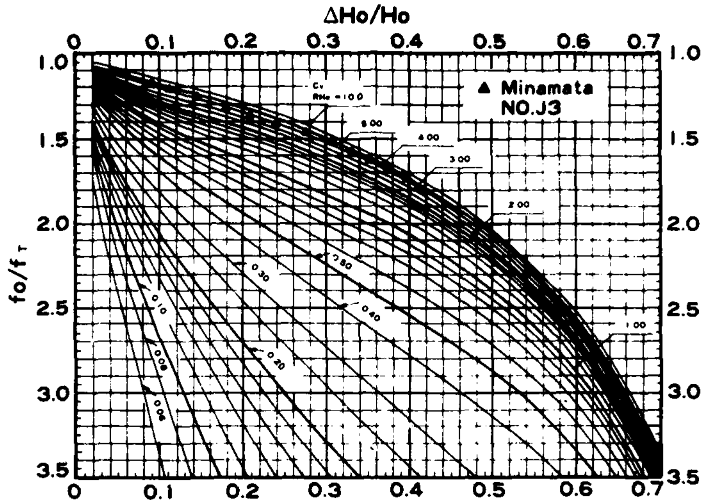

Fig.6 An example of CRS test data plotted on the f_O/f_T vs $\Delta H_O/H_O$ diagram

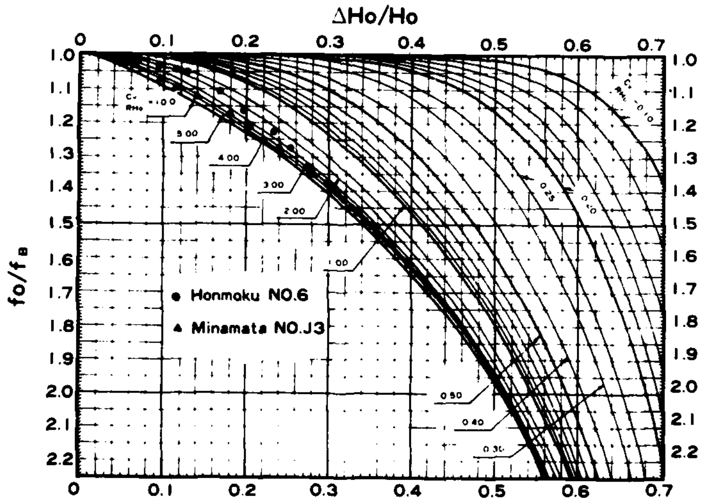

Fig.7 An example of CRS test data plotted on the f_O/f_B vs $\Delta H_O/H_O$ diagram

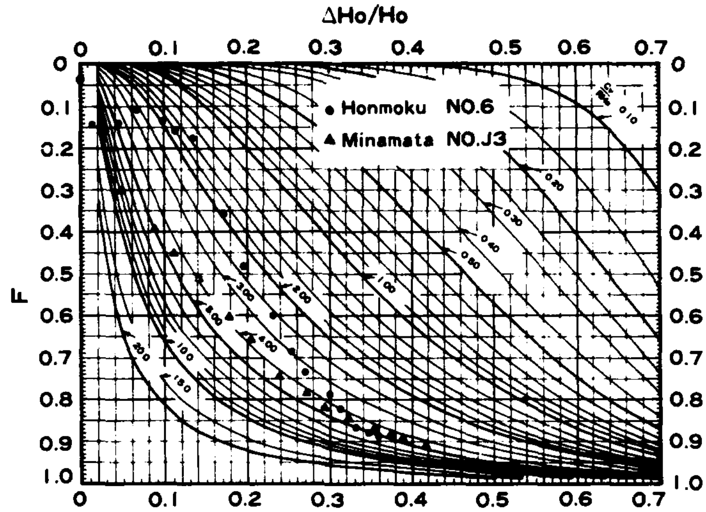

Fig.8 An example of CRS test data plotted on the F vs $\Delta H_0/H_0$ diagram

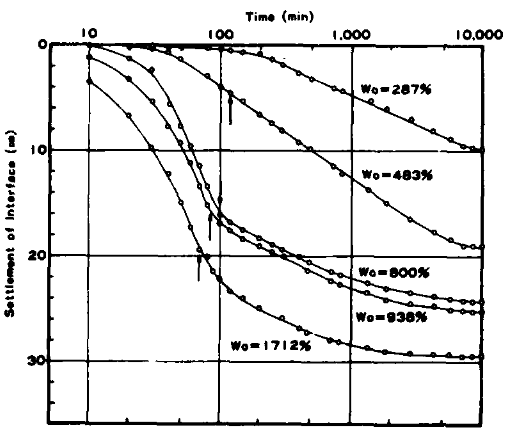

Fig.9 Typical examples of settling curves expressed on the logarithmetic time scale

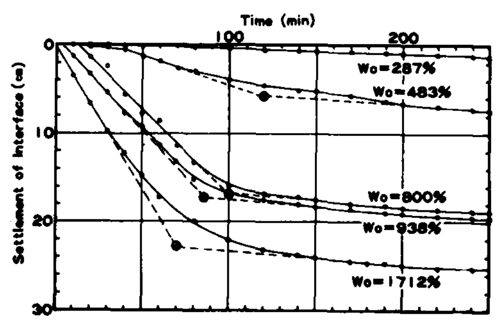

Fig.10 Typical examples of settling curves expressed on the arithmetic time scale

Use of Settling Test Results for Determination of Consolidation Constants in the Very Small Pressure Range

As a typical example, settling test results on Honmoku clay with 287 to 1712% of the initial water content are presented. Fig.9 and Fig.10 show settling curves, which trace the movement of the interface formed between the dispersion and clear water. The settling curves in Fig.9 are expressed on the logarithmic time scale, while those in Fig.10 are expressed on the arithmetic time scale to enlarge the behavior at the initial stage. The settling process of clay suspension with a high water content is usually classified into a flocculation stage, settling stage, and consolidation stage (Imai, 1980). It is difficult to distinguish clearly the time when the consolidation stage begins. One of the practical methods is to determine the starting time for self-weight consolidation as the intersection of two straight lines drawn on the settling curve as shown in Fig.10 (McRoberts and Nixon, 1975, and Imai,1980). The starting time for self-weight consolidation thus determined in Fig.10 is shown by arrows in Fig.9.

From these settling test results, it can be seen that the initial water content of the soil is an important factor governing the settling characteristics, especially in its influence on the time required for the beginning of the consolidation stage and on the ratio of settlement due to self-weight to the total settlement.

Settling test results can give useful information on the consoliation characteristics in the very small pressure range. The f-logσ' relation in the very small pressure range can be established from the settling test results using the method adopted by Yano, et al. (1977); that is, it can be determined from the water content distribution obtained after the completion of self-weight consolidation. In the present experiment, however, it is noted that the double tube type cylinders were used to obtain more accurate water content distribution by preventing the sliced sample from being compressed when it was extruded from the cylinder.

Fig.11 shows the f-logσ' relationships thus determined on Honmoku clay with different values of initial water content. It can be seen from Fig.11 that the initial water content influences the f-logσ' relationship in the small pressure range; however, the influence of the initial water content becomes less significant as it decreases.

On the other hand, the self-weight consolidation process observed in a settling test can give us information on the time rate of settlement in the very small pressure range. By assuming that the self-weight consolidation process for low water content follows Mikasa's consolidation theory (Mikasa, 1963), the Cv can be approximately determined by the curve fitting procedure using the computor program CONSOLID (Umehara and Zen, 1975) as shown in Fig.12.

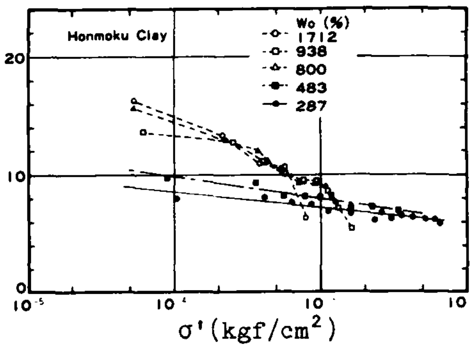

Fig.11 f-logσ' relation determined from settling tests (Honmoku clay)

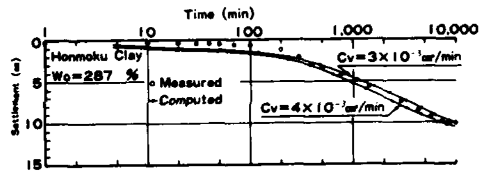

Fig.12 A typical example of curve fitting on self-weight consolidation process (Honmoku clay)

Consolidation Constants in the Wider Pressure Range

f-logσ' Relationship

Fig.13 shows the f-logσ' relation determined by three kinds of tests, settling tests, constant rate of strain consolidation tests, and conventional oedometer tests on Honmoku clays.

The f-logσ' relationship in the small pressure range is dependent on initial water contents. The f-logσ' relation for a higher initial water content has a steeper gradient than that for a lower water content. On the other hand, these compression curves for different initial water content tend to show some convergence in the larger pressure range. As a result, below some water content value the f-logσ' relationship is uniquely determined. The water content value at which this occurs may vary according to the soil type.

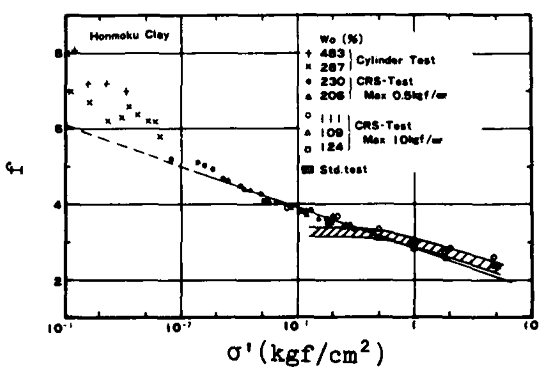

Fig.13 f-logσ'relation in the wider pressure range (Honmoku clay)

The f-logσ' relationship determined from the constant rate of strain consolidation tests in the higher pressure range shows a reasonably good agreement with the results obtained from the conventional oedometer tests, which were conducted on nine specimens preconsolidated in another ring up to $0.5 kgf/cm^2$. The straight line extended to the small pressure range almost coincides with the f-logσ' relationship obtained from the settling tests on the sample with a lower water content. Therefore, as far as the slope of the compression curve is concerned, the f-logσ' relationship in the small pressure range can be obtained for practical purposes by extending the straight line representing the f-logσ' relationship obtained from oedometer tests. It is desirable, however, to perform the consolidation tests in the actual pressure range expected because the f-logσ' relationship estimated by extrapolating may tend to be erratic.

Fig.14 to Fig.19 show the f-logσ' relationships for other marine sediments. These relationships were evaluated by conducting the constant rate of strain consolidation tests. The stress and pore water pressure transducers with the maximum capacity of $0.5 kgf/cm^2$ were used, due to the pressure range required for the estimation of consolidation settlement due to self-weight in the actual reclaimed soils. In addition, the supplementary information on the compression curve in the very small pressure range was also obtained by conducting the settling tests on each sample. It can be seen that the initial water content influences the compression curve for each sample. Its influence is typically represented in the cases shown in Fig.14 and in Fig.16; that is, the compression curve for the sample with a higher initial water content is subjected to the stronger influence of the settling process and has a steeper gradient compared with that of the compression curve obtained from the constant rate of strain consolidation tests. In cases when the initial water content decreases, the ratio of the consolidation settlement due to self-weight of the soil to the total settlement becomes more significant, and then the compression curves obtained from both the CRS test and the settling test tend to fall on the approximately common straight line.

From the considerations above, the approximately linear relation of f-logσ' may hold in the wider range of pressure for very soft soils with

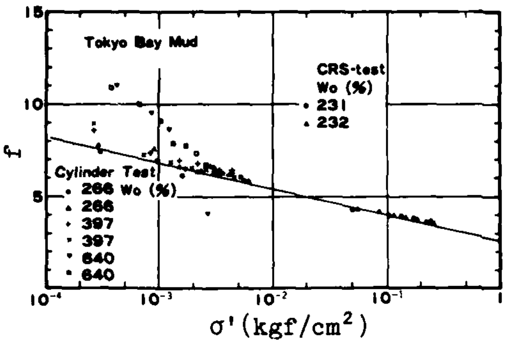

Fig.14 f-logσ' relation determined from both CRS tests and settling tests (Tokyo Bay muds)

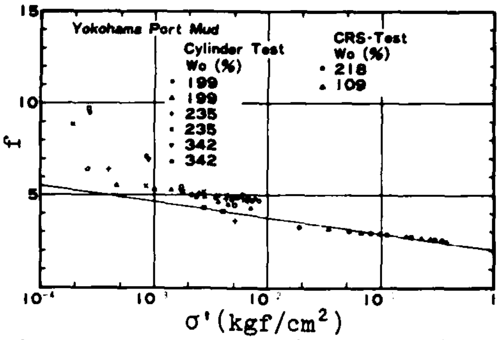

Fig.15 f-logσ' relation determined from both CRS tests and settling tests (Yokohama Port muds)

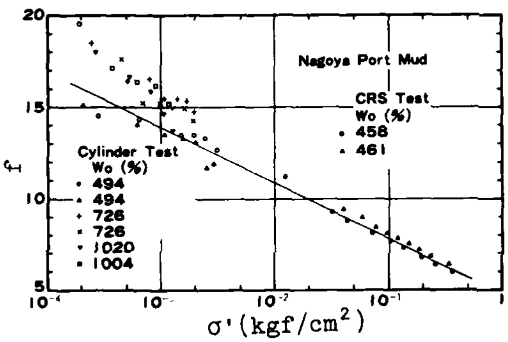

Fig.16 f-logσ' relation determined from both CRS tests and settling tests (Nagoya Port muds)

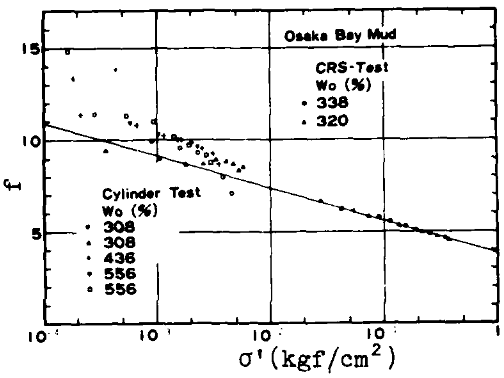

Fig.17 f-logσ' relation determined from both CRS tests and settling tests (Osaka Bay muds)

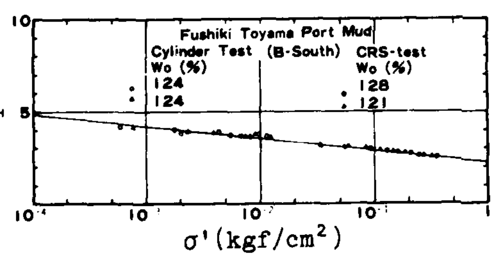

Fig.18a f-logσ' relation determined from both CRS tests and settling tests (Fushiki Toyama Port muds, B-south)

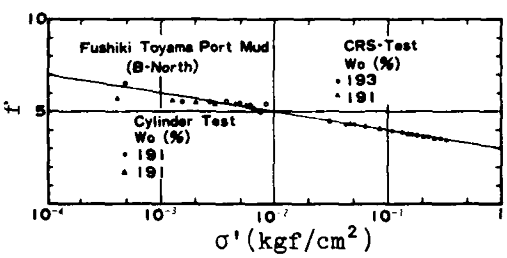

Fig.18b f-logσ' relation determined from both CRS tests and settling tests (Fushiki Toyama Port muds, B-north)

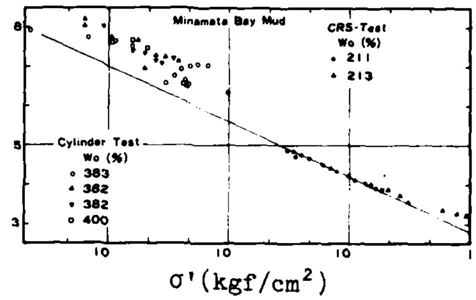

Fig.19 f-logσ' relation determined from both CRS tests and settling tests (Minamata Bay muds)

an initial water content less than some given value, within which the self-weight consolidation is dominant.

Coefficient of Consolidation, C_v

The variation of C_v with the average consolidation pressure, σ_{av}', in the wider range of pressure was examined for each sediment. Fig.20 shows the variation of C_v with the average consolidation pressure on Honmoku clay. The relationships between C_v and σ_{av}' were obtained from three types of tests such as settling tests, CRS tests, and conventional oedometer tests. It is said that normally consolidated clays generally have a reasonably constant value of C_v. However, the value of C_v in the wider pressure range for Honmoku clays does not show such a tendency, but increases with the increasing pressure.

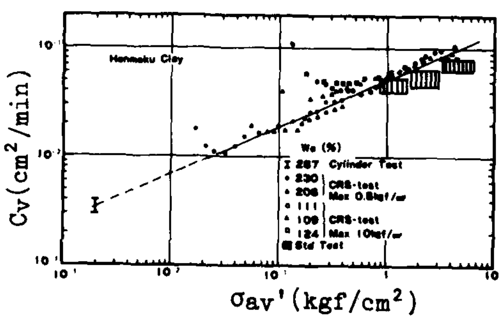

Fig.20 $\log C_v$ vs $\log \sigma_{av}'$ relation (Honmoku clay)

As for other marine sediments, Fig.21 to Fig.26 show the variations of C_v with the average consolidation pressure, which were obtained from the CRS tests by using the stress and pore water pressure transducers with the maximum capacity of 0.5kgf/cm^2. The C_v estimated from the settling test results by means of an approximating curve fitting procedure is also shown in each figure.

From these results, it can be seen that the values of C_v are generally dependent on the pressure; however, the degree of pressure dependency differs according to the soil type. Roughly speaking, the C_v at a specified pressure, say, σ_{av}'=1.0kgf/cm^2, becomes smaller for a higher value of plasticity index and the variation of C_v with pressure becomes smaller for the sediments with a higher plasticity index.

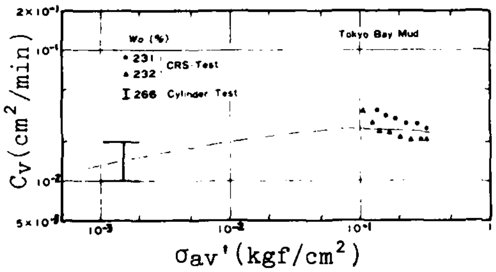

Fig.21 $\log C_v$ vs $\log\sigma_{av}'$ relation (Tokyo Bay muds)

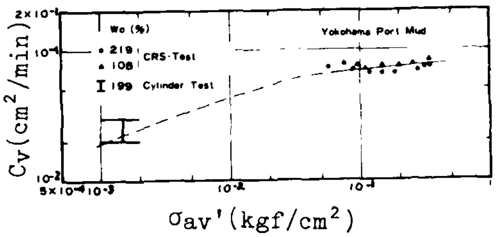

Fig.22 $\log C_v$ vs $\log\sigma_{av}'$ relation (Yokohama Port muds)

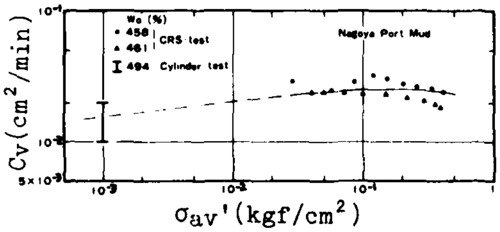

Fig.23 $\log C_v$ vs $\log\sigma_{av}'$ relation (Nagoya Port muds)

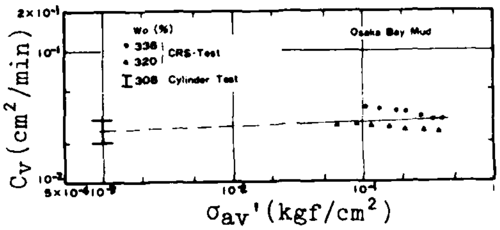

Fig.24 $\log C_v$ vs $\log\sigma_{av}'$ relation (Osaka Bay muds)

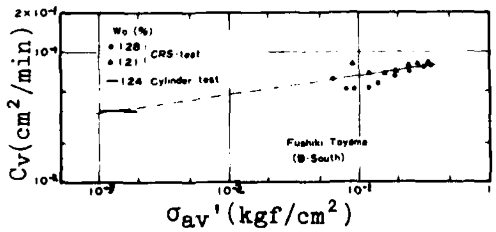

Fig.25a $\log C_v$ vs $\log\sigma_{av}'$ relation (Fushiki Toyama Port muds, B-south)

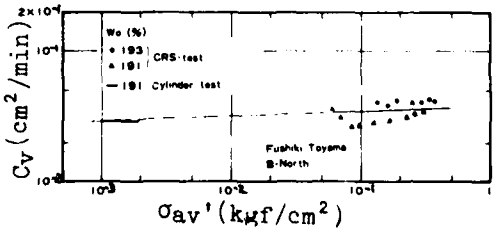

Fig.25b $\log C_v$ vs $\log\sigma_{av}'$ relation (Fushiki Toyama Port muds, B-north)

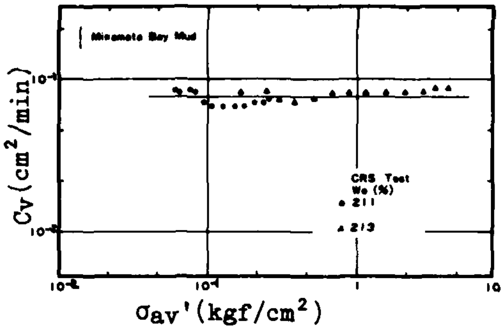

Fig.26 $\log C_v$ vs $\log \sigma_{av}'$ relation (Minamata Bay muds)

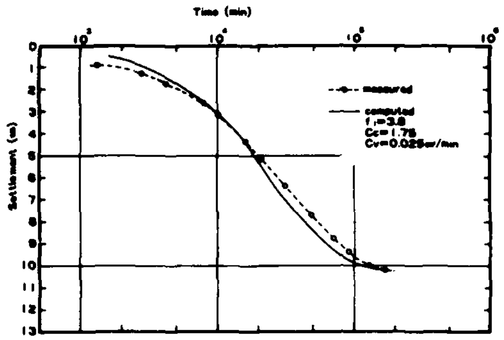

Fig.27 Settlement due to self-weight in the model fill

Table 4 Initial state of the model fill

Clay Thickness, H_o(cm)	80
Water Content, w_o(%)	303.3
Void Ratio, e_o	7.849
Volume Ratio, f_o	8.849
Moist Unit Weight $\gamma_t(gf/cm^3)$	1.180
Dry Unit Weight $\gamma_d(gf/cm^3)$	0.293

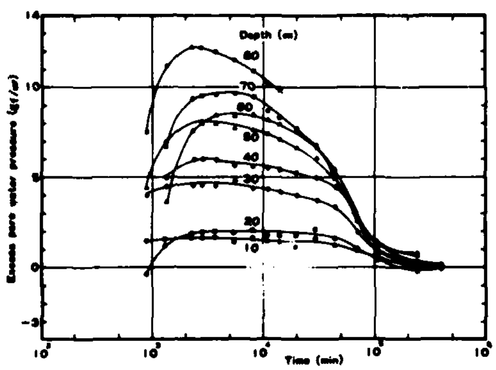

Fig.28 Excess pore water pressure vs time relation for each depth

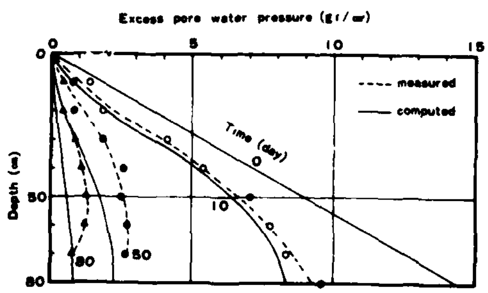

Fig.29 Excess pore water pressure distribution with depth for each time lapse

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MANAGEMENT OF BOTTOM SEDIMENTS CONTAINING TOXIC SUBSTANCES: PRO--ETC(U)
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APPLICATION TO SETTLEMENT ANALYSIS OF A RECLAIMED LAND COMPOSED OF VERY SOFT SOILS

Model Experiments on Self-Weight Consolidation and Its Analysis

The self-weight consolidation phenomena of the model fill produced by Osaka Bay muds were observed by measuring the settlement and the excess pore water pressure at several points in the model fill.

Fig.27 shows the observed settlement recorded at a location 10cm below the surface, while Fig.28 shows the observed excess pore water pressure recorded at several points in the model fill. It can be seen that the excess pore water pressure measured by each manometer shows a peak value 2 days after starting of self-weight consolidation and decreases gradually as the self-weight consolidation proceeds.

Experimental results on self-weight consolidation described above were compared with those calculated using the computer program CONSOLID (Umehara and Zen, 1976), in which the effect of self-weight and the change of the thickness of layer can be considered on the basis of Mikasa's consolidation theory (Mikasa, 1963). The calculation conditions were determined as follows:

The initial state of the model fill is shown in Table 4. From both the settling test and the constant rate of strain consolidation test results as described previously, the consolidation constants of Osaka Bay muds can be given as 1.75 for the compression index, C_c, 0.025cm^2/min for the coefficient of consolidation, C_v, and $f=f_1-C_c\log\sigma'=3.8-1.75\log\sigma'$, where $f_1=3.8$ corresponds to the value of f for $\sigma'=1.0$kgf/cm^2.

Thus, the computed settlement at a location 10cm below the surface is shown with the observed settlement in Fig.27. It can be seen that the computed settlement shows a reasonably good coincidence with the observed one. On the other hand, Fig.29 shows the comparisons between the computed and observed excess pore water pressure at each depth for each different time. The computed distribution of excess pore water pressure with depth for 10 days after shows a reasonably good coincidence with the observed one, while the computed distribution of excess pore water pressure with depth for either 50 days after or 80 days after shows a relatively poor coincidence with the observed one for each case. However, this is not caused by the improper selection of consolidation constants,

but on the technical difficulty involved in measuring the excess pore water pressure accurately during the long observation period.

From the considerations described above, it can be said that the self-weight consolidation phenomenon of very soft fill clays is satisfactorily estimated by using the constant rate of strain consolidation test results.

Application to the In Situ Reclaimed Land

In the management of contaminated sediments, it is necessary to obtain the space for disposal of dredged materials. For this purpose, it is important to estimate the total settlement and the rate of settlement during the process of both settling and consolidation. In addition, the consolidation characteristics of reclaimed soils that have completed self-weight consolidation are also required in the wider pressure range with respect to the utilization plan of the reclaimed land.

The consolidation constants for predicting self-weight consolidation are those covering the pressure range of 0.01 to 0.5kgf/cm^2, since the stress level induced by the self-weight of soils in the actual reclaimed land is considered to be within that range. The constant rate of strain consolidation test previously proposed can sufficiently cover that range of pressure.

Fig.30 shows a flow chart of a suggested procedure for predicting the settlement of very soft reclaimed land. Therein it is assumed that the settling process and the consolidation process can be separated as shown in Fig.9 and in Fig.10.

It is noted that in cases where the initial water content is very high, say , more than 200 to 300%, settling tests are occasionally required; on the other hand, in cases where the initial water content is less than about 200%, settling tests are not necessary.

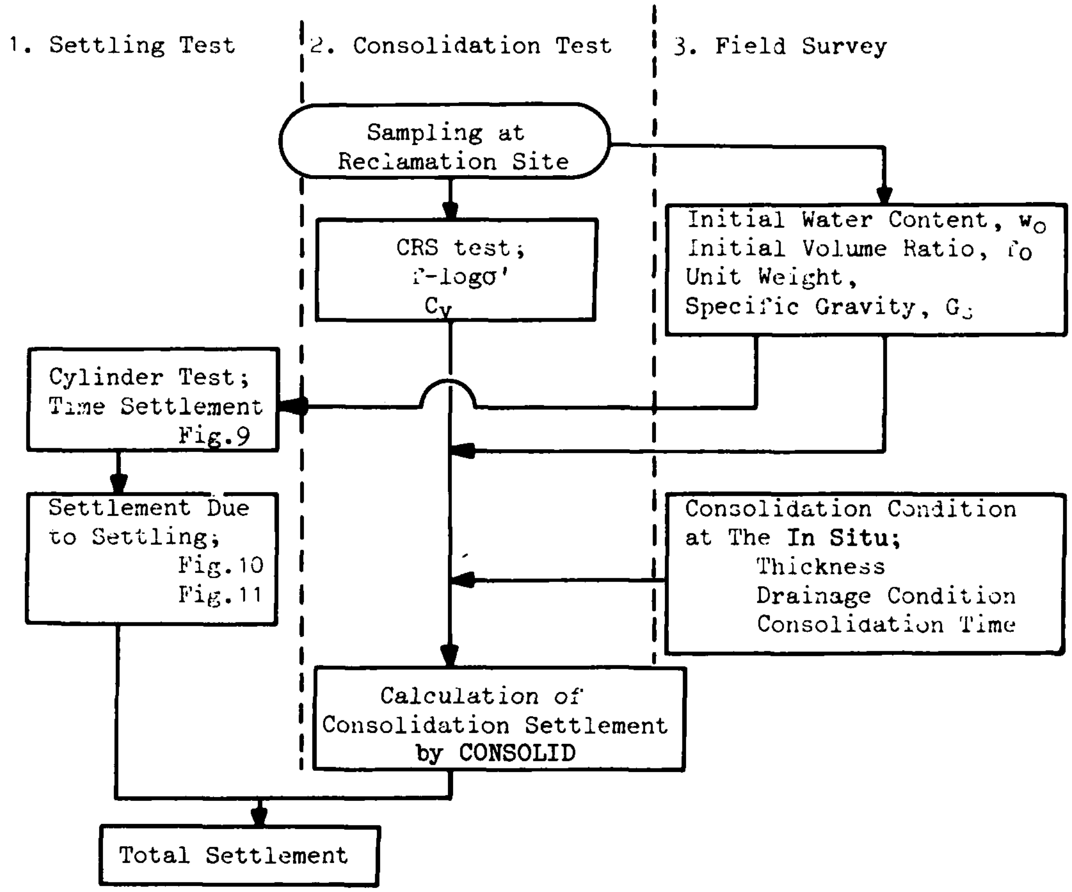

Fig. 30 Flow chart of settlement analysis of very soft reclaimed land

CONCLUSIONS

With respect to the dredging and reclamation for the management of contaminated bottom sediments, the consolidation characteristics of various contaminated sediments taken from several harbors in Japan were investigated using the previously proposed method for determining the consolidation constants of very soft soils. The settling test results were also used to investigate the consolidation characteristics of contaminated sediments in the very small pressure range. In addition, for one kind of contaminated sediments, the self-weight consolidation phenomena were observed in a model fill consisting of such materials.

From the investigation described above, the following conclusions can be drawn:

1) The compressibility of very soft soils in the very small pressure range is influenced by the initial water content, while its influence on compressibility becomes less significant in the larger pressure range.

2) An approximately linear relationship of f-$\log\sigma'$ holds in the wider pressure range for the soils with an initial water content low enough for the self-weight consolidation to become dominant.

3) The values of C_v for very soft sediments do not remain unchanged in the small pressure range, but increase with increasing pressure. The pressure dependency of C_v differs according to the soil type; that is, the pressure dependency of C_v becomes more significant in cases where the plasticity index becomes smaller.

4) The validity of the proposed method for determining the C_v and the f-$\log\sigma'$ relationship for very soft soils on the basis of the constant rate of strain consolidation is proven through the analysis of the self-weight consolidation phenomenon observed in a model fill.

5) A general procedure has been suggested to predict the settlement of very soft reclaimed land with respect to the management of the contaminated sediments.

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POLLUTION OF SEA WATER IN HACHINOHE HARBOR AND ITS RESTORATION BY SEDIMENT REMOVAL

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Abstract

With the industrialization around Hachinohe Harbor and the rapid economic progress in Japan, water pollution has advanced remarkably resulting in bad smelling seawater. Meanwhile the Prefectural Government of Aomori was urged to meet this environmental problem and in 1978 decided to remove the polluted sediment.

The whole area of the harbor was dredged from November 1979 until January 1981. This report outlines how the dredging was performed and how the removed sediment was managed, and also how the resulting water quality was improved.

1. Background of Hachinohe Harbor

Hachinohe Harbor is situated in the northern part of mainland Japan, and is now an important fishing port for northern sea fisheries (Fig. 1).

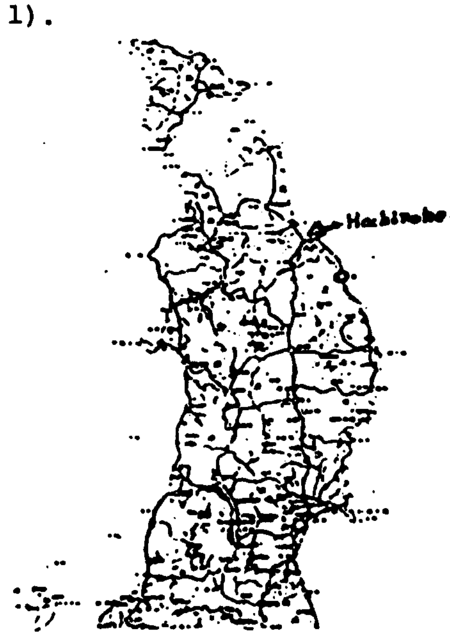


Fig. 1
Situation of
Hachinohe Harbor

In former times it was only a small fishing port, but after the war, with the high rate of progress in the Japanese economy it became an industrial and fishing port, because big firms like power plants, steel works, and chemical works, etc., were built around it.

Hachinohe Harbor consists of 3 sections (Fig. 2). The 1st Harbor was formerly a part of Mabechi River and in 1959 was built as a harbor by the deviation of the river route.

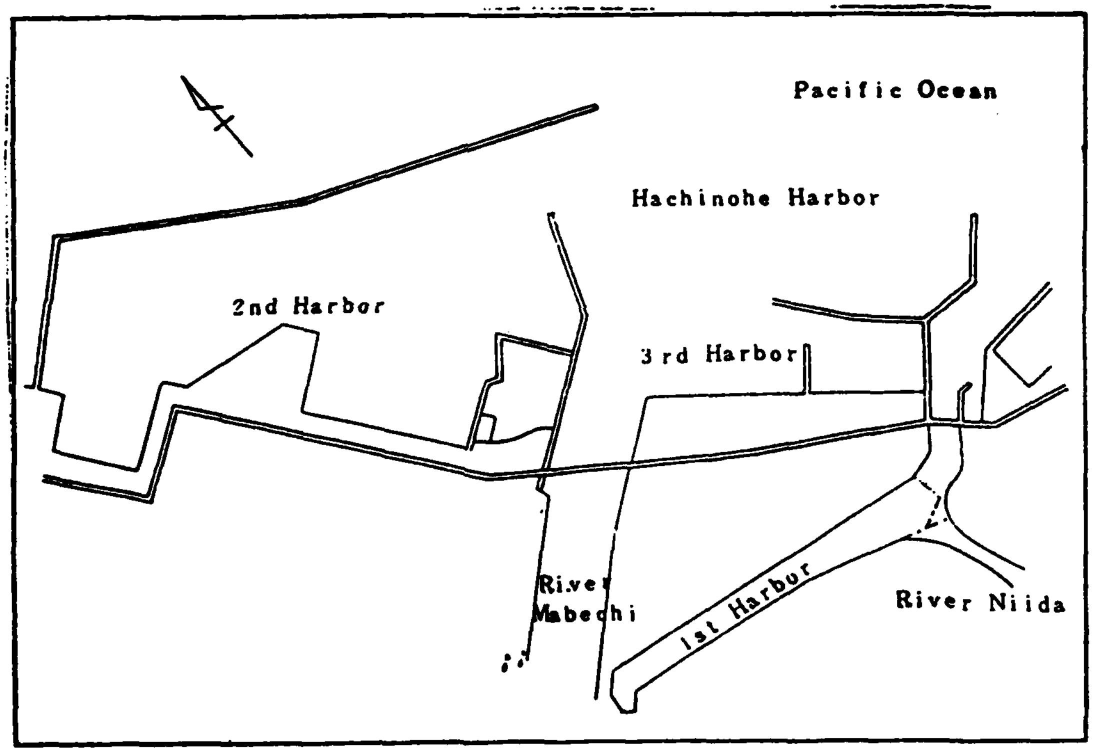


Fig. 2 Land Lay of Hachinohe Harbor

The 1st Harbor (hereafter 1st omitted) is rectangular in shape and has a size of 2500 m by 150 m. Its mean depth is 6 m.

The effluents of factories and urban drainage have flowed into this narrow space for a number of years and a lot of pollutants have accumulated in the sediment and polluted the seawater.

The concentrations of nutrients in water before dredging were about 25 - 50 ppm for T - N and 0.2 - 0.3 ppm for T - P. It is no wonder that such highly polluted seawater was considered an important environmental problem.

Needless to say, there are two methods to restore polluted seawater: restriction of influx loading and reduction of internal loading of pollutants. The Aomori prefectural government decided to undertake the latter, so as not to be dependent upon the former.

2. Sediment Analysis

Sediment analyses were carried out twice June 11, 1979, and September 1, 1979, and sediment samples were taken from 5 points (as shown in Figure 3).

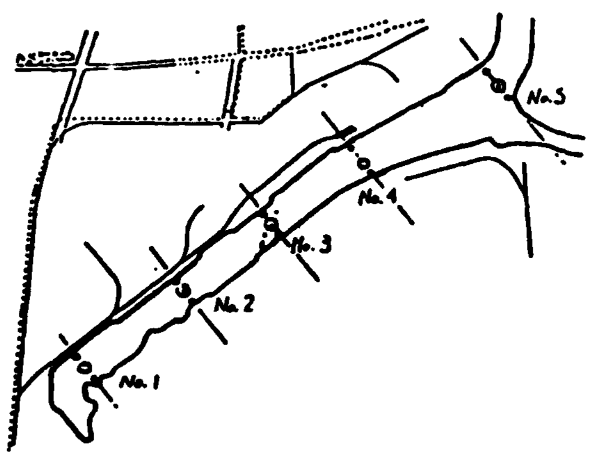


Fig. 3 Sampling Points

The results of the sediment analyses are shown in Table 1. As the table shows, the sediments are highly polluted.

The concentrations of COD, sulfide, T - N, T - P, and N - Hexan extracted matters are all high, especially those of sulfide and N - Hexan.

Table 1 Results of Sediment Analysis

			Water Content %	I.G. %	COD_{Mn} mg/g	Sulfide mg/g	T–N mg/kg	T–P mg/kg	N-Hexan mg/kg
№ 1	U	0–30 cm	238.9	15.1	68.5	8.9	3,630	1,750	23,300
	M	30–60	114.6	10.8	60.5	8.3	2,050	2,040	18,700
	B	60–80	74.5	7.5	38.5	10	1,230	1,640	16,000
№ 2	U	0–30	124.2	11.5	59.8	12	2,670	1,850	20,300
	M	30–60	118.3	13.5	66.2	13	2,620	1,880	19,900
	B	60–80	103.3	11.3	65.7	10	2,320	1,700	22,900
№ 3	U	0–30	176.2	16.0	89.5	3.3	2,570	1,910	18,500
	M	30–60	132.0	13.2	73.1	12	2,830	2,040	19,900
	B	60–80	115.9	11.9	71.5	9.1	4,510	1,940	23,300
№ 4	U	0–30	157.7	16.4	100	7.8	4,870	2,320	21,300
	M	30–60	107.9	15.7	70.0	12	3,850	1,620	27,700
	B	60–80	67.8	9.6	50.7	12	2,580	1,610	23,700
№ 5	U	0–30	155.8	16.1	80.0	4.5	4,350	1,620	6,080
	M	30–60	111.0	14.7	75.1	6.6	2,300	1,080	10,900
	B	60–80	103.7	14.8	77.0	10	2,730	1,130	10,000

The vertical distributions of these pollutants against sediment depth are indicated in Fig. 4, Fig. 5, and Fig. 6. As the figures show, the concentrations at upper layers and the ones at deeper layers are small. It seems that it approaches some value at a certain depth. It may be thought that the

upper portion of higher concentrations represents an accumulation of polluted sediment and the point of convergence, a background value proper to an unpolluted state.

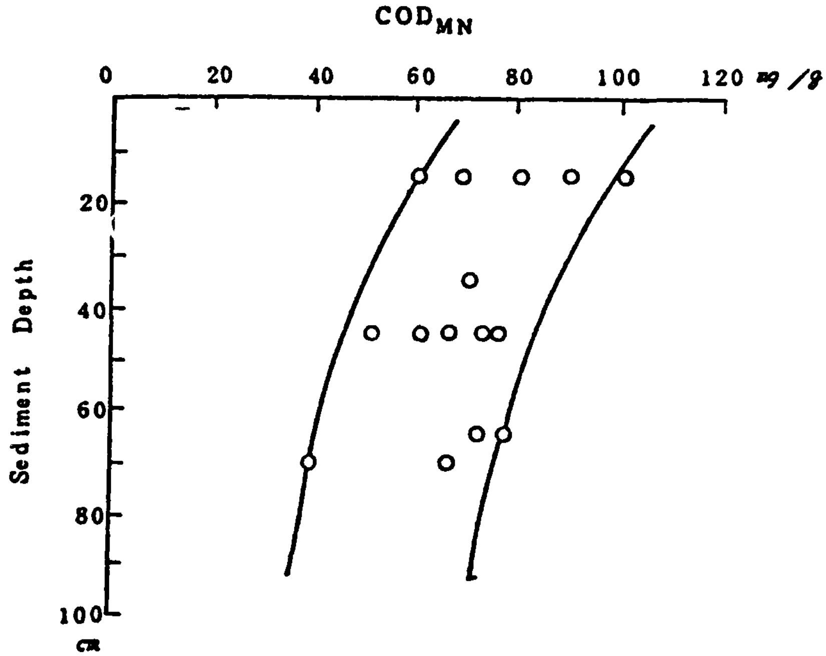


Fig.4 Vertical Distribution of COD_{MN}

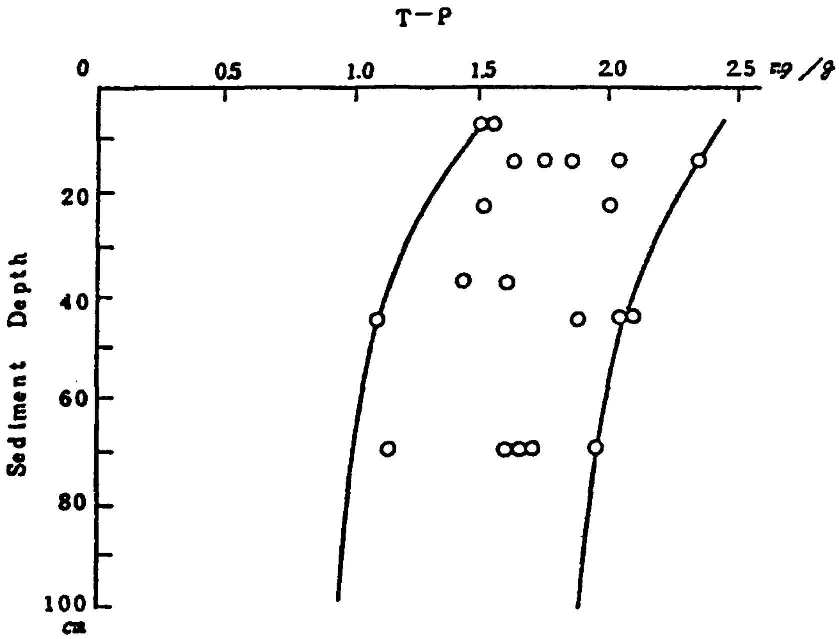


Fig.5 Vertical Distribution of T − P

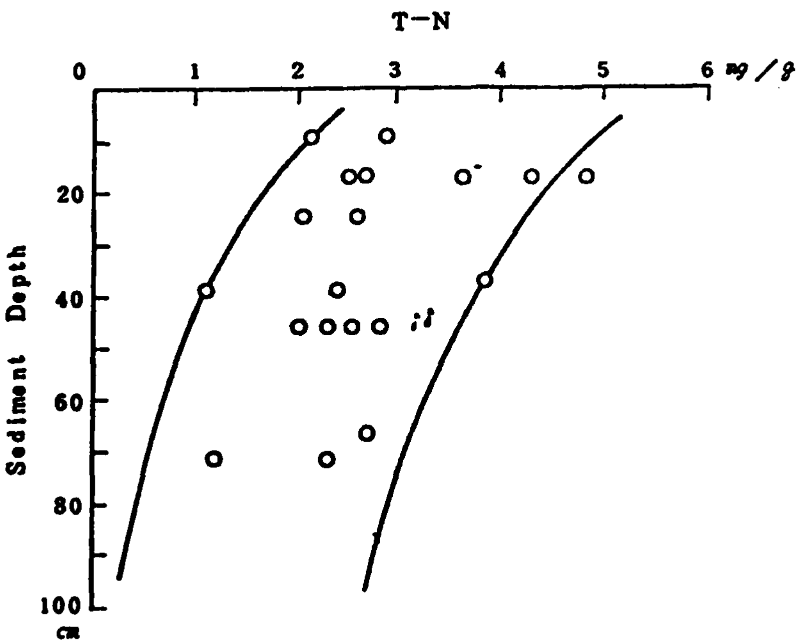


Fig.6 Vertical Distribution of T − N

3. Water Analysis

Water quality analysis was performed at the same times as the sediment analysis. Table 2 shows the analysis results of September 1.

Table 2   Results of Water Analysis

		Water Temp °C	SS mg/L	COD_{Mn} mg/L	N-Hexan mg/L	TOC mg/L	T−N mg/L	NH_4-N mg/L	PO_4-P mg/L	T−P mg/L	Cl ‰	Chl-a mg/m³
No. 1	U	23.1	35.5	6.1	0.3	7.4	24.78	1.59	0.08	0.291	12.809	229
	B	22.1	20.2	3.2	<0.1	2.0	4.2	0.28	0.11	0.130	10.411	13.5
No. 2	U	23.1	16.9	5.4	0.1	6.0	45.08	1.3	0.12	0.300	13.021	232
	B	22.1	19.7	2.4	<0.1	2.1	7.4	0.43	0.07	0.074	18.479	7.14
No. 3	U	23.1	38.5	6.1	0.1	7.3	49.42	1.34	0.15	0.310	13.765	302
	B	22.1	24.2	1.6	<0.1	2.0	9.66	0.46	0.08	0.093	18.497	14.8
No. 4	U	22.4	10.7	9.3	0.3	5.0	3.000	0.78	0.07	0.226	14.193	132
	B	22.1	24.4	5.5	0.1	2.0	5.04	0.15	0.04	0.053	18.513	13.1
No. 5	U	22.1	36.8	6.6	0.1	5.1	35.7	1.38	0.07	0.341	12.719	201
	B	22.1	23.8	2.4	<0.1	2.2	2.80	0.12	0.03	0.056	18.334	17.6

U = Upper layer 0.5 m below surface

B = Bottom layer 1 m above sediment

As the table shows, the seawater is extraordinarily eutrophicated. The high values of chlorophyll-a are also marked.

Such a high pollution of seawater is unprecedented in our country and represents the seriousness of the Hachinohe Harbor pollution problem.

It is worthwhile to notice that the concentrations at upper layers are large and the ones at deeper layers are small, as Fig. 7, 8, and 9 show.

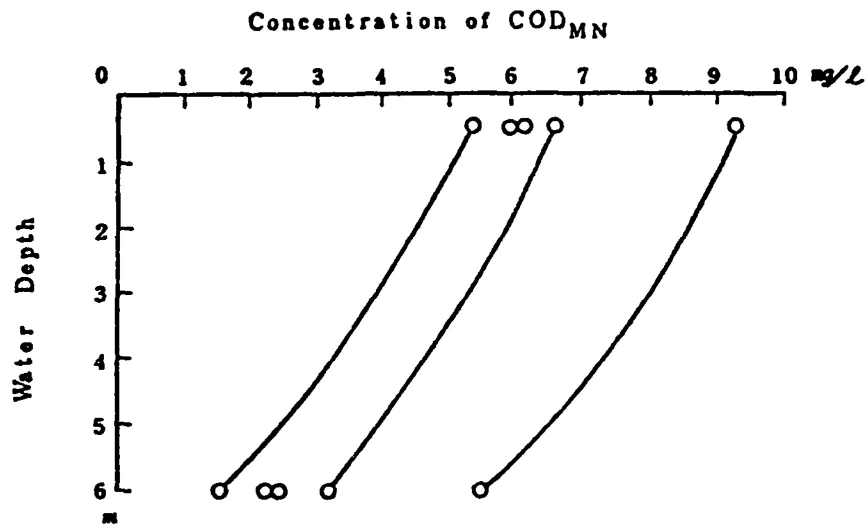


Fig.7 Vertical Distribution of COD_{MN}

Why such a vertical distribution occurs has been studied by Dr. T. Yoshida from the point of view of hydrostatical mathematics. His paper on this theme is presented in this proceedings. According to his theory, in water areas where pollutant particulates are released from sediment, the above-mentioned vertical profiles should be revealed.

Concentration of T - P

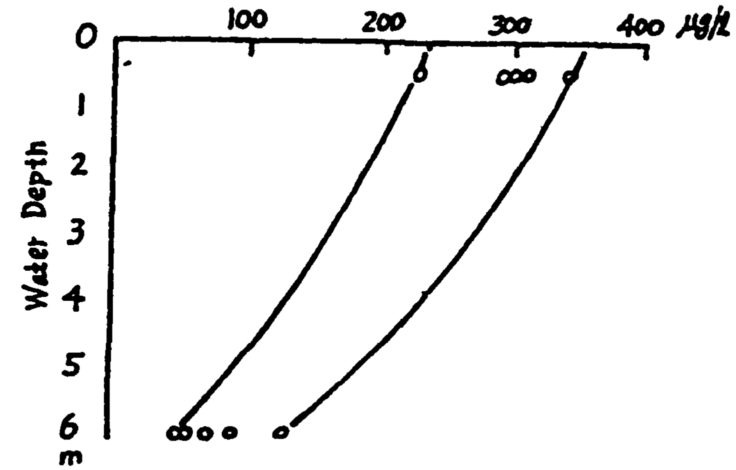


Fig. 8 Vertical Distribution of T - P

Concentration of T - N

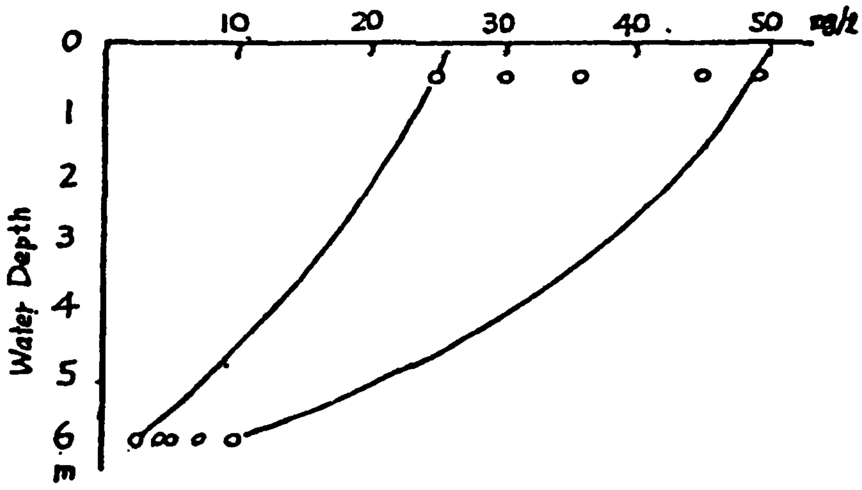
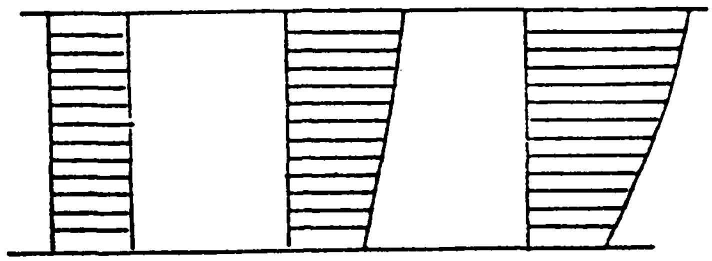


Fig. 9 Vertical Distribution of T - N

Therefore, the profile is dependent on the release rates. If the profile is a vertical line, no release occurs; that is, p_r (release rates) = 0. In the case that the concentrations

at upper layers are larger than the ones at bottom layers, release from sediment takes place. The more skewed the profile curve, the more the released quantities; that is, a larger p_r.



From this theory we can estimate that the release rates of T - P and T - N should be 0.19 mg/m^2/day and 17.8 mg/m^2/day, respectively. These values are in agreement with tests in the laboratory.

4. Gas Analysis

To examine the cause of the bad smell, gas collection was performed at the surface (90 cm below surface) and at the bottom (10 cm above sediment surface) at 3 points (No. 1, No. 3, and No. 5) for 3 hours (Figure 10).

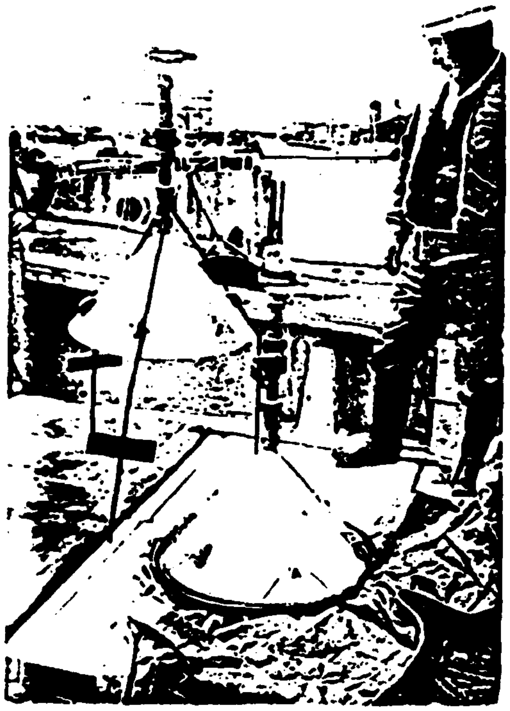


Fig. 10. Gas Collector

The gas was analyzed for hydrogen sulfide (H_2S) and methycaptan (CH_3SH) at the site and methane (CH_4) at the laboratory in Tokyo. The gas quantities collected were smaller than expected, 15.3 - 76.4 $ml/m^2/day$, except for 1162 $ml/m^2/day$ at No. 5 point. The concentrations of H_2S and CH_3SH were below 0.5 ppm and below 1 ppm, respectively. The concentration of methane gas was a maximum of 52.5 v/v % at the surface of point No. 5.

Table - 3 Generated Quantities of Gas

		Total generated quantities ml/m²/d	Methane	
			Concentration V/V %	Generation mg/m²/d
No. 1	Surface	76.4	1.0	0.543
	Bottom	15.3	0.2	0.021
No. 3	Surface	15.3	<0.1	0.011
	Bottom	15.3	<0.1	0.011
No. 5	Surface	1,162	52.5	436
	Bottom	76.4	<0.1	0.054

From the data of Shibaura Channel in Tokyo Bay and Hachinohe Harbor, a distinct relationship was found between generated quantities of gas and concentrations of sulfide in sediment (Fig. 11).

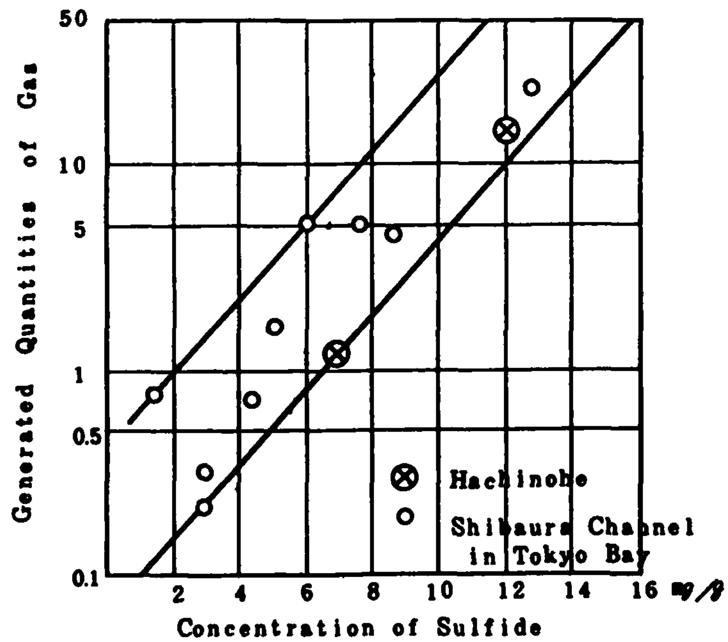


Fig. 11 Relationship between Generated Quantities of Gas and Sulfide

5. Biological Analysis

To examine the biological state of the harbor bottom, sediment samples were taken from a 1000-m area at 75 points by an Eckman sampler. The number of species and individuals in this region are shown in Table 4.

Table 4 Benthic Community Characteristics

Kinds of Species	№ 1	№ 2	№ 3	№ 4	№ 5
Pachydrilus Nipponicus	36.6	2,975	1,081	47.1	0
Pachydrilus Sp	0	0	0	47.1	0
Pontodrilus Sp	0	0	0	0	460
Asychio Sp	0	0	0	23.6	0
Boccardia Proboscidae	1,037	893	0	47.1	0
Hemipodus Spp	0	0	17.2	23.6	0
Lumbrinevis Sp	0	0	0	0	1,150
Namanereis Quadraticaps	0	42.5	17.2	0	192.4
No.of Species	2	3	3	5	3
No.of Individuals	1,403	3,910	1,115	189	1,801
$BI = \frac{\text{No.of Individuals}}{\text{No.of Species}}$	702	1,303	371.8	37.7	604

Among the species found, Pachydrilus nipponicus and Boccardia proboscidae dominate.

The number of species ranged from 2 to 5. The number of individuals was 1403 - 3910, except 189 at point 4.

The numbers of meiobenthos were as follows

No. 2	1,440,000	cells/kg
No. 3	3,480,000	"
No. 4	15,900,000	"
No. 5	4,930,000	"

They are in good proportion to the COD_{MN} concentrations in sediment, as Fig. 12 shows.

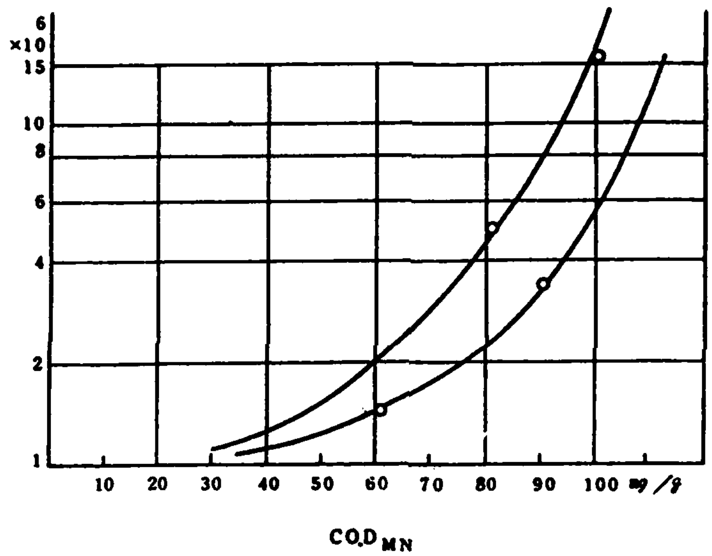


Fig. 12 Relationship between number of individuals and COD_{MN} in sediment

6. Dredging

Dredging was carried out during the period from Nov. 27, 1979, to Jan. 11, 1981 (Fig. 13). The total amount of dredged materials was 241,100 m^3 during 401 days.

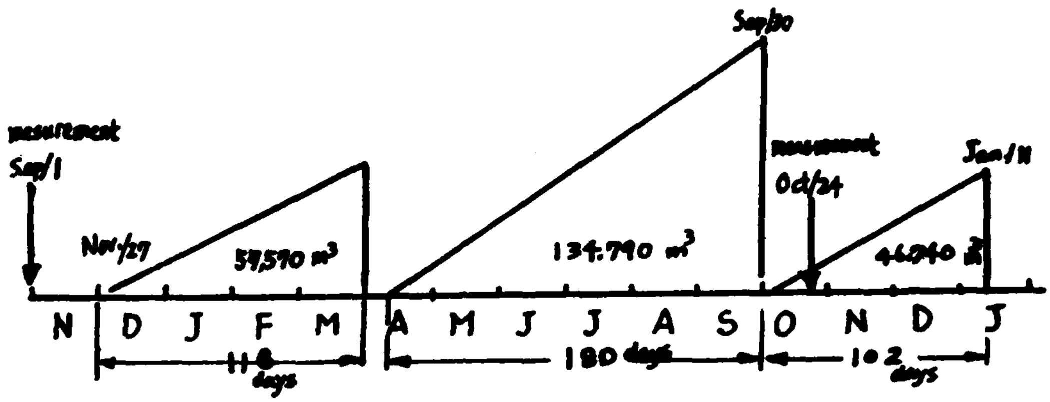


Fig. 13 Finished Schedule of Dredging

According to sediment properties 2 types of dredging were employed, that is, hydraulic and grab dredging, 72 % for the former and 28 % for the latter.

The hydraulic dredge has a capacity of 500 m^3/h and is equipped with a special suction device preventing turbidity. The total horsepower of the Diesel engine is 3360 PS.

Two kinds of grab dredge were used. The bigger one had a capacity of 400 m^3/h and a 6-m^3 grab. The smaller one had a capacity of 100 m^3/h and a 2-m^3 grab. The total horsepower was 480 PS (D.E.) and 44 PS (D.E.), respectively. The fleet consisted of these dredges and 4 barges (2 x 500 m^3, 2 x 200 m^3) and 3 tug boats (2 x 500 PS, 1 x 180 PS).

The removed sediment depth was about 50 cm, and was dredged in two cuts. The shallow water depth of 4 - 5 m and the appropriate removed depth of 50 cm were advantages when dredging, but the congestion of ships in the narrow harbor and the existence of numerous obstacles on the sea bottom were disadvantages. However, as a whole, the dredging went very favorably.

7. Management of Dredged Materials

The dredged materials were conveyed hydraulically to the disposal site by a pipe system 3500 m long that crossed two railways, one road, and one river (Fig. 14).

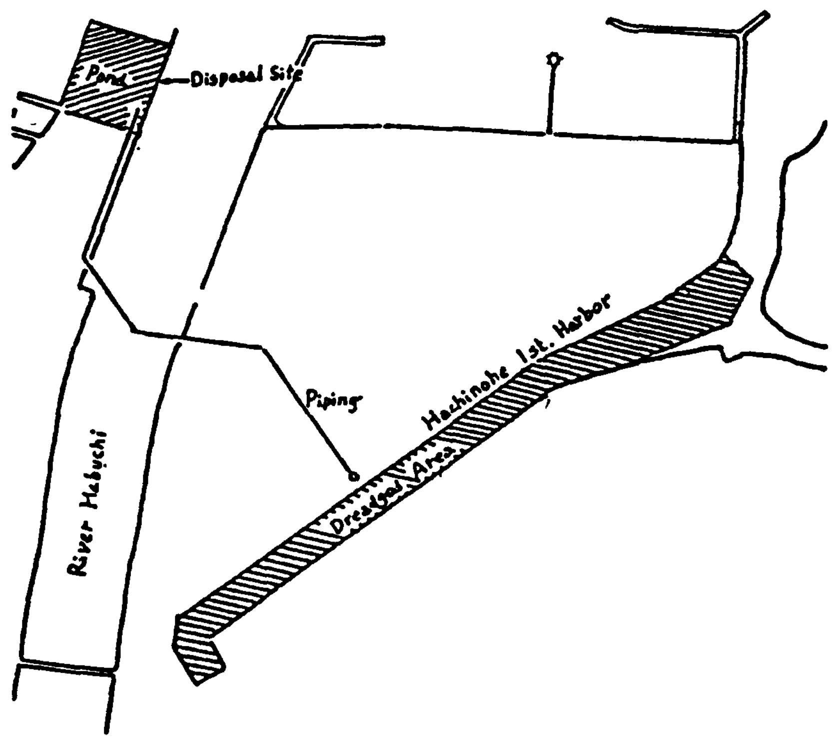


Fig. 14 Conveying and Disposal of Dredged Materials

The disposal pond had a volume capacity of 1,567,000 m^3 and a mean depth of 7 m. It was diked on all sides. The settling pond was located in the disposal ponds. Its volume was 27,450 m^3 and its depth was 3 m (Fig. 15).

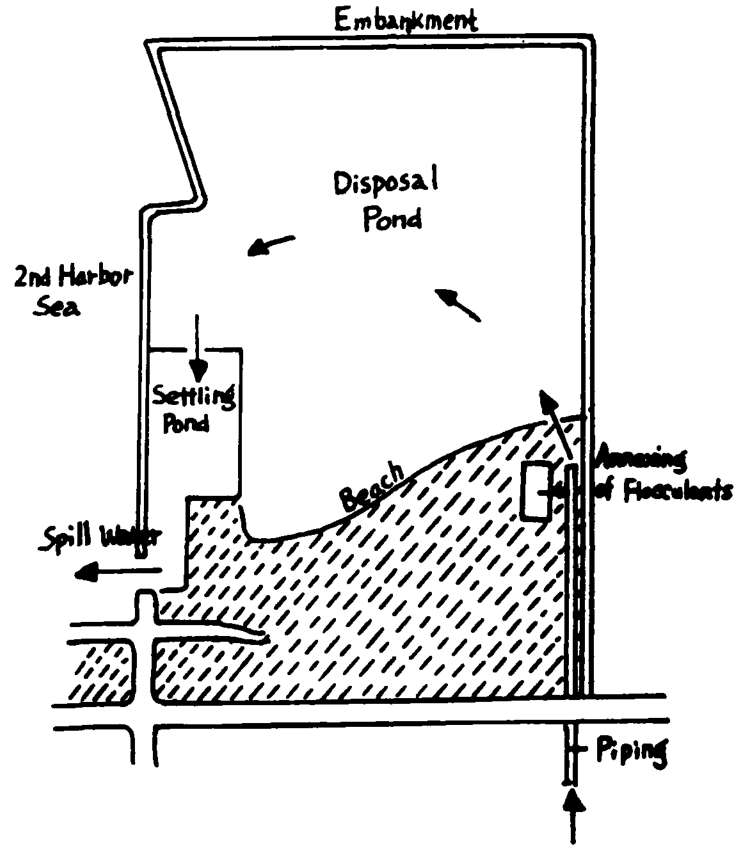


Fig. 15 Disposal Pond

A flocculent mixing plant was located at the pipe discharge point; from it flocculents were annexed directly into the pipe.

During most of the discharge operation, no flocculent was annexed; however, in the latter parts, it was necessary to annex 3 - 5 ppm of flocculents.

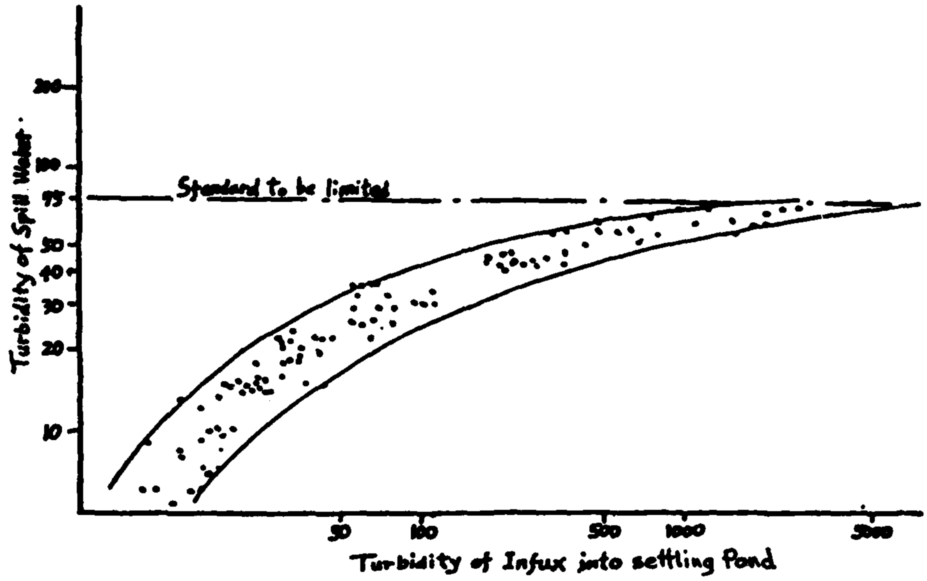


Fig. 16 Turbidity of Spill Water

The spill water quality was kept satisfactory under the limited level of discharge. The turbidities of the spill water are plotted in Fig. 16.

8. Results of Sediment Removal

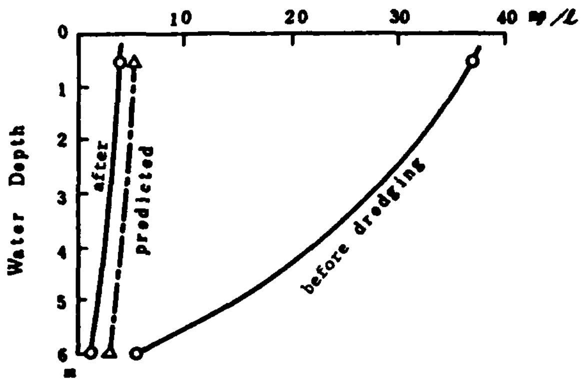
To investigate the effects of dredging, water quality was measured on Nov. 24, 1980, 50 days after the completion of dredging. The water quality data measured are summarized in Table 5.

Table 5 Water Quality Data

	№ 1		№ 2		№ 3		№ 4		№ 5	
	U	B	U	B	U	B	U	B	U	B
Temperature O	14.8	15.7	14.7	15.8	15.1	16.5	15.0	16.5	15.3	16.5
H_2 ion	8.0	8.1	8.0	8.1	8.1	8.2	8.1	8.3	8.2	8.3
DO mg/ℓ	6.1	7.1	6.2	6.9	5.8	5.4	6.2	6.6	6.3	7.1
SS mg/ℓ	3.4	2.9	2.3	2.6	2.5	3.8	3.0	3.8	6.0	7.1
COD mg/ℓ	4.7	3.5	4.9	3.9	5.0	2.6	5.6	3.4	4.4	4.2
T−P mg/ℓ	0.179	0.086	0.258	0.086	0.236	0.031	0.116	0.030	0.077	0.048
T−N mg/ℓ	3.72	2.27	3.92	2.11	3.95	0.59	1.69	0.71	1.47	0.71
Cl_2 ‰	14.04	16.94	13.84	17.05	14.33	17.64	14.07	18.14	15.09	18.22
※1 n-Hexan mg/ℓ	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
※2 n-Hexan mg/ℓ	<0.01	−	−	−	0.07	−	−	−	<0.01	

※1. By JIS K0102 18.2
※2. By JIS K0102 18

The comparisons of nutrient concentrations before and after dredging are plotted in Fig. 17 and Fig. 18 with respect to the mean values of the 5 points.



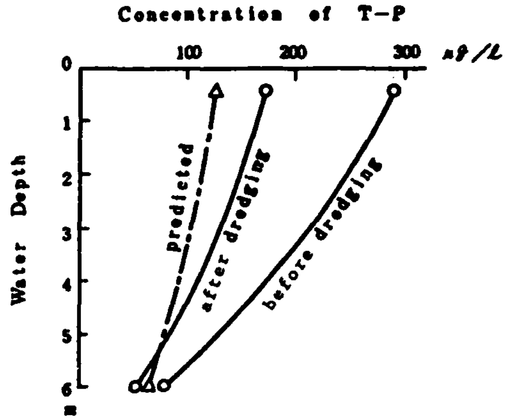


Fig. 17 Vertical profiles of T - P before and after dredging

Fig. 18 Vertical Distribution of T - P

As regards T - N, the concentration before dredging was 37 ppm at the surface, but it became only 2.95 ppm after dredging. Regarding T - P, the concentration before dredging was 293.6 μg/l, but it became 173.2 μg/l after dredging. As the figures show, the vertical profiles changed remarkably.

From the changes of profiles it is presumed that the release rates of T - P were reduced from 0.19 mg/m^2/d to 0.098 mg/m^2/d and the release rates of T - N from 17.8 mg/m^2/d to 0.54 mg/m^2/d. It was found that sediment removal resulted in a quite larger effect on T - N than on T - P. These results are beyond our expectations and suggest the importance of internal loading from sediment.

9. Change of Biological Phase

The biological samples were taken from 3 points (right shore, center, left shore) for each of the 5 sets points. The numbers of species and individuals at each point are shown in Table 6.

Table 6 Numbers of Species and Individuals

Kinds of Species	№ 1	№ 2	№ 3	№ 4	№ 5
Nemertinea					
Nematoda	33	124	388	34	45
Anaitides Maculata	33		33		
Eteone Sp					45
Hesionidae	33				
Neanthes Virens					
Nephtys Polybranchia					
Lumbrineris Sp			33		126
Doruilleidae	648	149	33	154	45
Pseudopolydora Kempi	12,314	4,061	5,627		1,561
Prionospio Krusadensis					
Cirratulus Cirratus			33		262
Cirriformia Sp					
Capitella Capitata		2,819	2,673	1,569	649
Chone Teres	615				45
Nebalia Bipes					
Paranthura Japonica					
Corophium Sp	33				
Pinnixa Rathbuni					
Styela Sp					
No.of Individuals	13,610	7,153	8,820	1,757	2,778
No.of Species	7	4	7	3	8
BI	1,944	1,788	1,260	586	347

As shown in Table 4, the total number of kinds of species before dredging was 8; it became 20 after dredging (Table 6). The number of individuals ranged from 188 to 3910 before dredging and increased to the range from 1757 to 13610 after dredging. Regarding their mean value, they change from 140 to 6824. That is, the number of individuals after dredging increased immensely to about 50 times as many prior to dredging. The dominating species before dredging were Pachydrilus nipponicus and Boccardia proboscidae, but after dredging, Pseudopolydora kempi and Capitella capitata.

As mentioned above, the sediment removal brought a great change in benthic community characteristics; the biological environment at the sea bottom was considerably improved.

In Fig. 19 the relationships between the number of species and the BI number before and after dredging are plotted. It represents vividly the great effect of dredging upon biological phase.

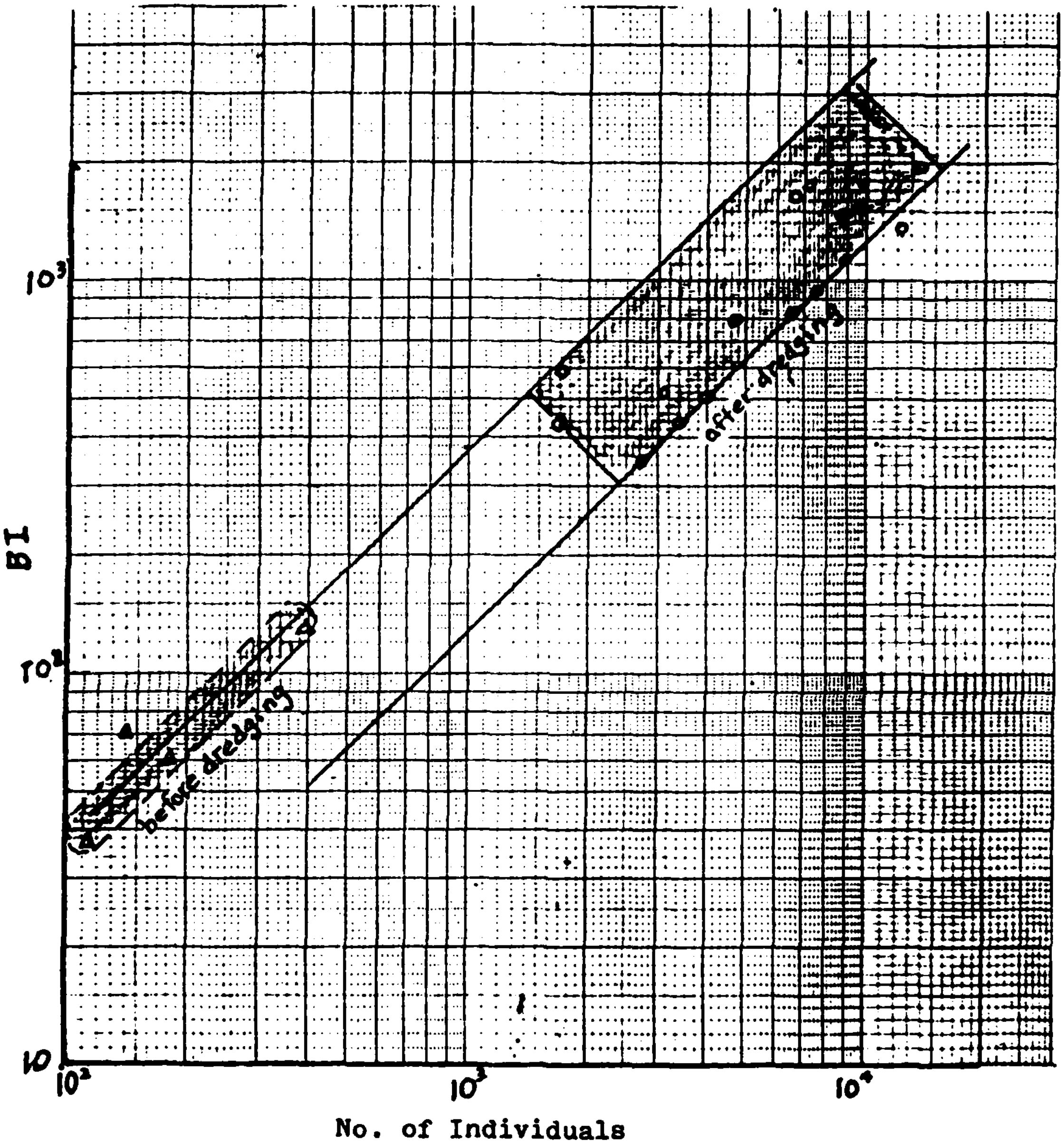


Fig. 19 Relationship between BI and No. of Individuals

The number of microbenthos was in the range from 295,920 to 1,147,870 before dredging. It changed to the range of 216,242 to 20,034,607 after dredging. Regarding their mean value, it changed from 54,460 to 3,236,754; that is an increase of about 6 times.

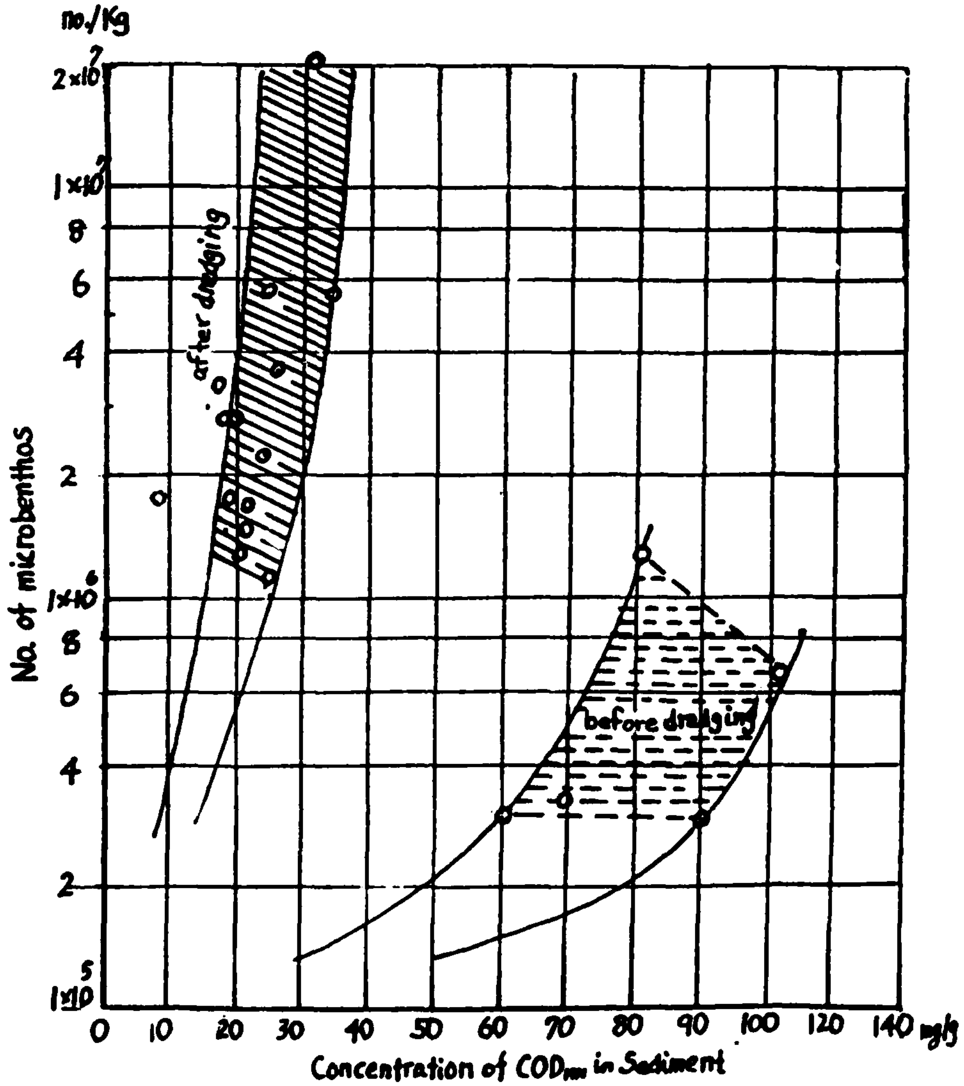


Fig. 20 Relationship between No. of Microbenthos and COD_{MN}

10. Conclusions

To restore the polluted seawater in Hachinohe Harbor, about 200,000 m^3 of sediment was dredged. The sediment removal resulted in an unexpected improvement of water quality and the biological environment. Regarding nutrient concentrations, the changes from before to after dredging were as follows:

	before	after	
T - N	37.0 mg/l	2.5 mg/l	(mean value)
T - P	293.9 μg/l	173.3 μg/l	(mean value)

The released quantities of nutrients from sediment were reduced to the utmost extent.

Such an example as Hachinohe Harbor, namely that all the sediment was removed within one year and its effects were immediately examined, is unprecedented in our country.

It is very informative to us, in the respect that an internal loading of pollutants plays a greater role upon water quality than generally expected.

THE DISPOSAL OF SEDIMENTS DREDGED FROM NEW YORK HARBOR

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ABSTRACT

New York Harbor is the leading port in the United States. Its continued viability depends upon the ability to maintain its channels and berthing areas through dredging operations. Because of many issues, primarily the fact that harbor sediments are contaminated with a wide range of pollutants from wastewater discharges and ocean disposal has been the primary disposal option, dredging operations have encountered problems. Biological test results indicate that New York Harbor sediments are relatively non-toxic. In addition, the majority of sediments tested do not appear to have a strong biaccumulation potential for harmful contaminants. All feasible disposal options are being pursued in an integrated and cooperative approach. Emphasis has been placed on identifying disposal options for contaminated sediments.

INTRODUCTION

New York Harbor, also known as the Hudson/Raritan Estuary and the Port of New York and New Jersey, is located within the most urbanized area in the United States. It provides a natural border between the States of New York and New Jersey (Figure 1). The Harbor accepts the fresh water input from four major rivers (the Hudson, Raritan, Passaic, and Hackensack Rivers), and is largely composed of salt water derived from the Atlantic Ocean. The Harbor exhibits the characteristics of a partially mixed estuary.

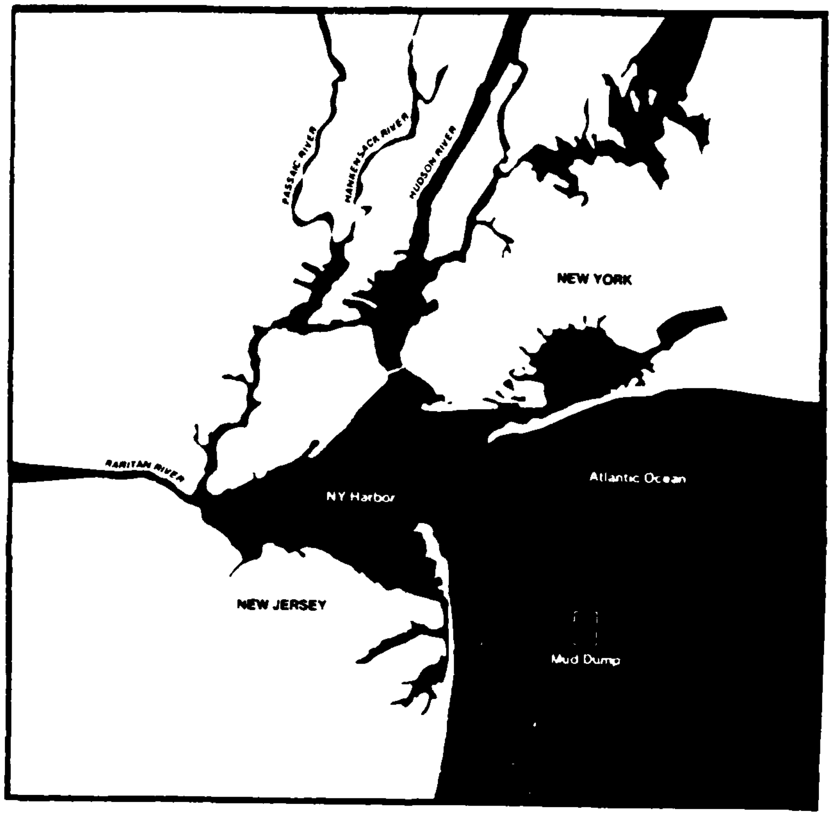

Figure 1. New York Harbor showing major rivers and "Mud Dump"

New York Harbor is of prime economic importance to the metropolitan region and the nation. In terms of both cargo tonnage and ship arrivals, New York Harbor is ranked as the leading United States port. Total cargo passing through the Harbor in 1978 was approximately 165,000 metric tons (1), while oceanborne ship arrivals exceed 10,000 per year (2). The Harbor with its 34 petroleum-handling terminals and 14 general cargo facilities is directly responsible for 60,000 port-related jobs and $4.5 billion in revenues (2,3). Petroleum products account for greater than 75% of the total tonnage of cargo entering the Harbor.

Within the Harbor, there are approximately 380 kilometers of Federally maintained waterways. Navigation channels used by ocean-going vessels are maintained to depths ranging from 9 to 14 meters while the smaller commercial recreational boat channels have depths from 2 to 5 meters. Most of the shipping channels are not naturally deep. For example, the main entrance channel to the Harbor has a natural depth of 5.5 and is presently maintained to a depth of 14 meters.

Over the past fifty years, an average of approximately 7.6 million cubic meters of sediment was annually dredged from the Harbor area. The total volume of material in the past has been highly variable because of sporadic shorefront and channel development. In recent years the annual dredging volumes have ranged from 5.5 million cubic meters (1970) to 14.8 million cubic meters (1971). Dredging associated with the construction and maintenance of Federal channels accounts for approximately 70% of the annual dredging volume. Maintenance dredging associated with all Harbor activities is estimated at about 4.5 million cubic meters annually.

The waterways adjacent to New York City have been used for the disposal of a large quantity and variety of waste, including dredged material. The earliest reference to ocean disposal in the New York area dates back to 1683 (4). In addition to dredged material, ocean dumping of sewage sludge, construction debris, acid, and chemical wastes still continues.

Since 1888, disposal operations for dredged material have been conducted under permits issued by the Federal Government. Historically, ocean disposal sites were located close to shore and in relatively shallow water. However, due to shoaling problems created by disposal operations, the designated sites have been moved successively offshore. The current dredged material disposal site, known as the "Mud Dump", is approximately 11 kilometers east of New Jersey and 20 kilometers south of New York. This places it near the head of the Hudson River Canyon in an area with water depths ranging from 18 to 27 meters. Since 1914, most of the material dredged from New York Harbor has been taken to the "Mud Dump". At present, over 90% of all Harbor dredged material is placed at the "Mud Dump".

PROBLEM

The problem in New York Harbor during the past three years has been the delay in carrying out dredging projects and the uncertainty of conducting dredging in future years. The Port Authority of New York and New Jersey (2) and McDonald (3) have provided summaries of the dredging dilemma. Though at first glance, the problem would appear to be simple, the issues behind the problem are highly complex and have frustrated the Port Community, legislators, government administrators, and environmental interest groups.

The first issue is the fact that New York Habor is not a naturally deep port and it receives a continual flux of sediments from upstream sources, most of which deposit within the Harbor confines. As previously mentioned, the Harbor generates at least 4.5 million cubic meters of material each year requiring maintenance dredging.

Since the metropolitan region is highly populated and industrialized, the Harbor receives the discharges of approximately 11 million cubic meters per day of industrial and domestic wastes (5). Associated with these discharges are a wide variety of organic and inorganic contaminants. These contaminants are strongly attracted to sediment particles. It is this situation that has generated most of the concern regarding the dredging and disposal activities.

The potential environmental impacts associated with the disposal of contaminated sediments have been vocalized by a keenly aware American public and has resulted in several legislative acts which have brought about strict regulations regarding the proper disposition of dredged sediments. Of particular concern to New York Harbor has been the passage into law of the Marine Protection, Research and Sanctuaries Act of 1972, or more commonly known as the "Ocean Dumping Act". This law regulates all types of ocean dumping, including dredged material. In accordance with the "Ocean Dumping Act", regulations and criteria were promulgated by the U.S. Environmental Protection Agency (EPA) to determine the acceptability of material for ocean disposal.

In the case of dredged material, these criteria augmented the regulatory program of the U. S. Army Corps of Engineers (Corps) which has primary responsibility for regulating all forms of construction activities in waters of the United States, including ocean waters.

The Ocean Dumping Criteria have had considerable effect upon operations in New York Harbor since most material dredged from the Harbor has been dumped at offshore sites in the Atlantic Ocean. Since the New York Harbor region has been highly developed for decades, disposal sites (i.e., upland disposal or within-harbor disposal) are not available for the vast quantity of material dredged from the Harbor. New York Harbor has been dependent upon ocean dumping for continued viability for over 65 years (6).

The Ocean Dumping Criteria became effective in 1977. It was determined at that time that prior regulatory methods of determining ecological effects of proposed dumping activities were grossly inadequate. The new criteria called for a testing protocol that was more rigorous than any similar United States regulatory program (Table 1). The Criteria specified biological tests to consider short-term toxicity of dumping operations and the potential for long-term chronic effects through the bioaccumulation of harmful contaminants. The implementation of the Criteria resulted in considerable scientific debate. The interpretation of biological test results was subjected to scrutiny by four U. S. Government Agencies and the general public. Even though a guidance manual had been published jointly by the Corps and the EPA, there were conflicting technical arguments regarding threshold toxicity and bioaccumulation levels at which ocean dumping requests could be granted.

TABLE 1. TESTING REQUIRED FOR AUTHORIZATION TO DISPOSE OF DREDGED MATERIAL AT THE "MUD DUMP"

PHYSICAL	BIOLOGICAL	CHEMICAL
Grain size Analysis	Bioassay (Test and Control) 1. Liquid Phase 2. Suspended Particulate Phase 3. Solid Phase	Bioaccumulation (Test and Control) Elutriate

The interpretation of test results has resulted in one legal action brought against the Corps by the National Wildlife Federation. U. S. Government scientists have been working together closely during the past year to develop uniform interpretive guidance.

In summary, the lack of available disposal options, the continual contamination of Harbor sediments by waste discharges, the "state-of-the-art" testing and evaluation procedures, and the confusion of dredged material with other materials such as sewage sludge have all contributed to curtailment of dredging.

RESULTS

The open-water disposal of dredged material has been the subject of considerable research since 1973. References 7,8,9, and 10 provide excellent summaries of the open-water disposal research conducted during the Dredged Material Research Program. Conner et al. (11) includes a summary of research efforts as they pertain to the ocean disposal of sediments from New York Harbor. The significant results of research to date indicate the following:

-Material falls to the bottom rapidly upon dumping and very little material escapes the immediate vicinity of the dumping operation.

-Dumping at the "Mud Dump" since 1914 has resulted in a large mound having a miximum thickness of about 9 meters and an areal extent of over 10 square kilometers.

-Very little material appears to have been eroded from the "Mud Dump".

-The dumping operation results in no release or very insignificant releases of contaminants from dredged material to the surrounding water column.

-Dumped material is finer grained than continental shelf sediments.

-From the data available it does not appear that bioaccumulation of contaminants by marine organisms residing in the vicinity of the "Mud Dump" is different from other areas in the New York Bight.

-The greatest influence on water quality in the New York Bight comes from the tidal exchange of waters from New York Harbor.

As mentioned previously the Criteria took effect in January 1977. The Criteria stressed the importance of determining effects through direct biological testing. Thus bioassays were adopted as appropriate tests for determining the net toxicological effect on marine organisms of dumping dredged material. A Corps/EPA implementation manual (12) was subsequently published delineating procedures for conducting biological testing; the New York District of the Corps, in conjunction with Region II of EPA, developed a regional guidance document (13) to implement the required testing procedures.

The biological testing associated with the Ocean Dumping Criteria involves a liquid, suspended particulate, and solid phase bioassay. Organisms surviving the solid phase testing are tested for body burden concentrations of certain contaminants. The procedures for conducting these tests are contained in the Corps/EPA Implementation Manual (13).

The liquid and suspended particulate phase bioassays are conducted to predict short-term impacts to the water column during a dumping operation and shortly thereafter. Three species are used in both bioassays. The results of an individual bioassay are expressed as a LC50 (lethal concentration of liquid or suspended particulate phase to disposal site water whereby 50 percent of the organisms died). These results are then interpreted in light of mixing and dispersion which could be anticipated after dumping. Figures 2 and 3 show the results of liquid and suspended particulate phase bioassay data submitted to the New York District for regulatory review.

The highlighted percentages on Figures 2 and 3 indicate at what LC50 value the "limiting permissable concentration" or LPC, would be exceeded for a typical dumping operation at the "Mud Dump".

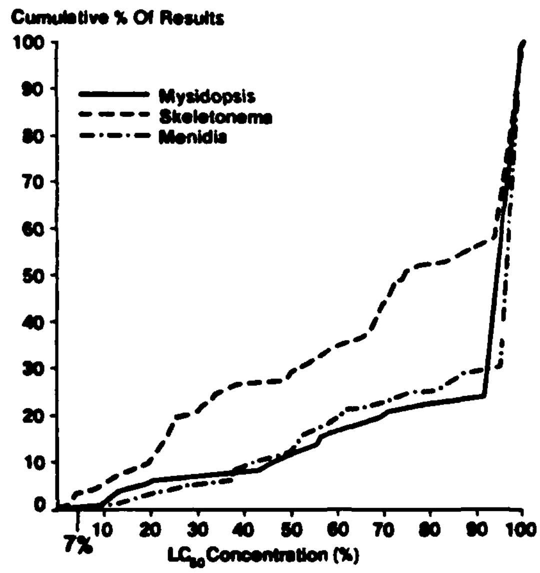

Figure 2. Results of liquid phase bioassay testing expressed as cumulative percentage. LC50 values of 7% or less would result in the limiting permissible concentration being exceeded

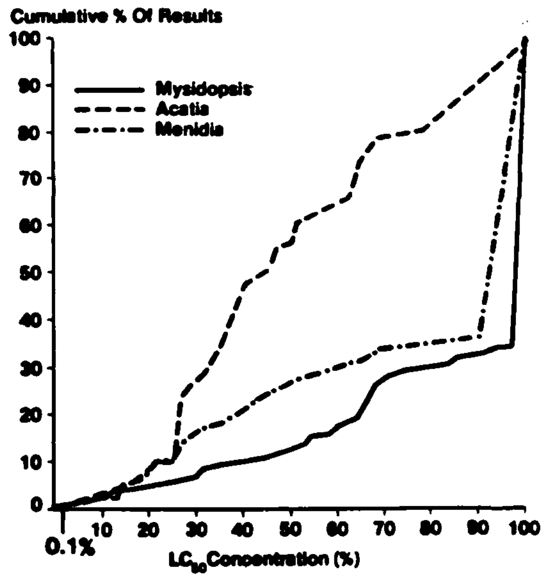

Figure 3. Results for suspended particulate phase bioassay testing expressed as cumulative percentage. LC50 values of 0.1% or less would result in the limiting permissible concentration being exceeded

An LPC is defined by the Criteria as being 0.01 multiplied by the LC50 value of the bioassay in question. The Criteria are not satisfied when either the calculated concentration of liquid or suspended particulate phase cannot be diluted to below the LPC. The highlighted values on Figures 2 and 3 therefore indicate at what point the LPC has been exceeded and potential unacceptable water column impacts are anticipated.

In Figure 3 it can be seen that the LPC has never been exceeded in the suspended particulate phase. For the liquid phase (Figure 2), the LPC has been exceeded about 3% of the time for Skeletonema costatum. In those cases where the LPC was initially exceeded, the permit applicant was directed to increase his vessel speed during dumping or decrease his rate of dumping. By accepting these conditions, the Criteria could be satisfied and a permit could be issued. These bioassay results confirm research results mentioned above that water column impacts associated with dumping are nonexistent or insignificant.

The interpretation of test results from benthic or solid phase bioassays surfaced a few problems. Mysid shrimp (Mysidopsis bahia) were utilized as one of three test species. Based upon several sets of mysid mortality data, it appeared that this organism was the most sensitive of the three to dredged material being tested. However, due to the erratic nature of the testing data submitted by different laboratories, controlled experiments were conducted for the New York District to ascertain why the substantive differences were occurring. It was found that the mysids were more sensitive to test conditions (i.e. size of aquaria, handling, suspended particles, etc.) than to the dredged material itself. Therefore, mysids were not considered appropriate for future use in solid phase bioassays.

In February of 1979, the New York District and Region II EPA revised their region guidance document to include the requirement of laboratory bioaccumulation analyses. This involved the retention of surviving organisms from the solid phase bioassays and subsequently analyzing them by species for cadmium, mercury, petroleum hydrocarbons, PCB, and DDT.

Figure 4 is a summary of solid phase bioassay results expressed as a frequency distribution. The results represent differences in survival between the control and dredged material test for the total community. The total community values are the average survival percentages of all three species being tested.

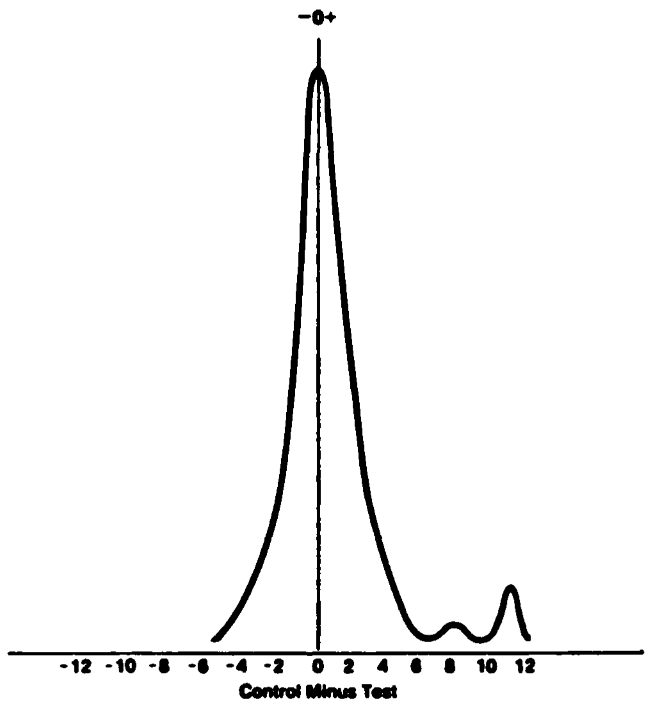

Figure 4. Frequency distribution for solid phase bioassay testing for total community. Numbers expressed represent differences in survival between control and test

Species used in the solid phase testing are Mercenaria mercenaria (hard clam), Palaemonetes sp. (grass shrimp), and Nereis sp.(polychaete worm). It can be seen from Figure 4 that the curve is slightly skewed toward greater test mortality. In only 3 cases out of 121 have mean survivals for control and test been statistically significant at the 95% confidence interval and the difference between control and test mean survival been found to exceed 10%. Survival differences of less than 10% are not thought to be of ecological significance (13).

Table 2 contains the results found to date on bioaccumulation in organisms surviving the solid phase testing. The numbers indicate the percentage of times when the bioaccumulation values found in the test were greater than the control by a statistically significant amount. In almost one half of the tests, significant amounts of petroleum hydrocarbons were detected. The concentrations that were found in these cases ranged from 0.18 ppm to 77.86 ppm. In contrast, DDT has not been found in significant amounts. In only two cases has DDT been found above detection limits.

The results for polychlorinated biphenyls (PCB) indicate that bioaccumulation in Nereis virens is much more common than in the other two species. Statistically significant values for the worm have been as high as 0.62 ppm. Bioaccumulation concentrations for the other two species have been low, with values generally below 0.1 ppm. Bioaccumulation of PCB appears to be statistically correlated with uptake of petroleum hydrocarbons. The bioaccumulation of mercury and/or cadmium is found only in a few projects. In all but one case, bioaccumulation of both metals from the same sediment has not occurred. To date only one project containing cadmium in statistically significant amounts (0.48 ppm in Palaemonetes pugio) has been approved for ocean disposal. This disposal was permitted with the mitigative measure of "capping".

The procedures for conducting bioassays and the interpretation of bioassay and bioaccumulation results have been subject to varied criticism. This certainly is understandable and welcome since these tests have only recently been applied to dredged material and such interpretive techniques have never before been routinely part of a large-scale regulatory program. The interpretation of laboratory bioaccumulation data was initially qualitative since numerical standards for contaminants in tissues have not been developed which allow for the prediction of long-term chronic impacts. As a result of the "PCB concern" last winter, the Corps and EPA developed an interpretive numerical limit for test species exhibiting statistically significant elevation of PCB.

TABLE 2. BIOACCUMULATION RESULTS EXPRESSED AS PERCENTAGE IN WHICH TEST RESULTS WERE GREATER THAN CONTROL RESULTS (STATISTICALLY SIGNIFICANT AT 95% CONFIDENCE LEVEL)

	Palaemonetes	Mercenaria	Nereis
Pet. Hyd.	42%	46%	46%
PCB	6%	12%	42%
DDT	0%	0%	0%
Hg	3%	4%	1%
Cd	1%	6%	6%

The values were based upon best available scientific information concerning chronic impacts, biomagnification, bioconcentration, and PCB levels in marine organisms in the New York Bight. The interpretive guidance is regional in nature and is currently being used by both the New York District and Region II-EPA.

The bioassay and bioaccumulation results from the New York District's regulatory program are consistent with the findings of the Dredged Material Research Program. Short-term inpacts of ocean disposal can be reasonably predicted and are in general of minor significance. The long-term significance of having mounds of contaminated dredged material on the ocean floor is not as clearly understood. In order to determine whether long-term chronic impacts are occurring as a result of dredged material disposal, significant advances in our basic understanding of contaminant-induced effects must be accomplished along with better monitoring strategies which can be applied in the field.

SOLUTION

The solution to the dredged material disposal controversy in New York Harbor is as complex as the problem itself. The ultimate solution is to have a sound management strategy which can clearly predict the most environmentally sound and economically feasible disposal option for the dredged material in question. Within this framework, dredging projects can be planned and carried out in a timely fashion thereby maintaining economic integrity of the Port while at the same time protecting environmental resources.

The Corps (14) has developed a plan to consider all available disposal options for the New York Harbor area. As mentioned previously, results of biological testing of Harbor sediments have revealed that the majority can be disposed of in ocean waters without causing environmental degradation. However, it appears that some Harbor sediments should not be dumped at sea without special handling because of toxicity and/or unacceptable bioaccumulation potential, and some material (i.e., sand) should be treated as a natural resource and put to good use. In addition, it is difficult at this time to determine whether ocean disposal is the ultimate disposal option for most Harbor sediments, since other alternatives have not been examined in sufficient detail to make meaningful comparisons.

Conner et al. (11) provide an assessment of potential dredged material disposal options for New York Harbor sediments. Each disposal option was subjected to a screening criteria from engineering, economic, environmental, public health and welfare, social acceptability, and legal/regulatory areas of consideration. The options considered were principally obtained from the results of a multi-disciplinary workshop held in 1977 (15). Connor et al. (11) determined that disposal options could be sorted into three basic categories. These are:

1. Those alternatives which are "not currently reasonable" (i.e. deep ocean disposal, offshore island containment, and no future dredging).

2. Those alternatives which may be "possible in special cases". This category involves the use of limited amounts of dredged material which have special characteristics (i.e. sand placement on beaches and use of dredged material as sanitary landfill cover).

3. Those alternatives which may be "feasible for large volumes of material". This category at present contains 3 options; shallow ocean disposal (i.e. disposal at the "Mud Dump"), placement of material in underwater depressions created by sand and gravel mining operations, and confined upland disposal.

Though Conner et al. (11) have provided a foundation for a dredged material disposal strategy for New York Harbor, only ocean dumping and small-scale beach nourishment and upland disposal are options immediately available for implementation. The Corps has developed a comprehensive study program to intensively investigate the disposal options suggested by Conner et al. (11), and to incrementally implement the feasible options into an overall management plan for the Harbor. An intergovernmental steering committee composed of Federal and State (New York and New Jersey) representatives has been established to guide the efforts of the study program. Major emphasis has been placed on those options which can be utilized for highly contaminated sediments. Two options have attracted considerable attention. Both consider the "capping" of "contaminated" sediments with "clean" material. One of the options involves "capping" within the "Mud Dump". This disposal strategy was implemented last year. Approximately 750,000 cubic meters of "contaminated" sediments were precision dumped at a taut-moored buoy located within the disposal site. These sediments

were subsequently "capped" with over 1.5 million cubic meters of sand dredged from the Harbor's entrance channels. An intensive monitoring program is underway to determine the placement accuracy, physical stability of the cap, and the effectiveness of sealing off potentially harmful contaminants from the marine ecosystem. The second "capping" option is to place contaminated sediment in depressions within New York Harbor (subaqueous borrow pits) which have been created through sand and gravel mining. These depressions could then be "capped" with "clean" sediments to isolate the contaminants. This option is still in the research phase with a pilot program scheduled for later this year.

The overall study effort for all disposal options is scheduled to be completed in 1984 at a cost of over $4 million. Continued inter-governmental cooperation and public involvement are thought to be key elements in the success of the program. It is hoped that this overall dredged material management strategy will lead to a predictable program of dredging in order for New York Harbor to maintain its preeminence as the United States' leading port.

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HOW TO DREDGE UP AND TREAT BOTTOM SEDIMENT IN THE RIVER WAKA

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1. The outline of the River WAKA

As Fig. 1 shows, there are 6 rivers in WAKAYAMA city: the River KINO, which is one of the largest rivers in Japan; the River WAKA, whose name has been changed from WAKA to SANADABORI in the northern part of Japan; the River ARIMOTO and the River DAIMON, which join the River SANADABORI; and the River ICHIBORI, which branches off the River WAKA and empties into WAKAYAMA port.

The 5 rivers, excluding the River KINO, are generally termed the UCHIKAWA.

The River WAKA, which relates to the subject of this paper, runs through busy sections of WAKAYAMA city.

Because of the severe pollution status of the river, it has been diverted and presently flows via the River ICHIBORI, into WAKAYAMA port.

Table 1 shows the general characteristics of the basin of the UCHIKAWA.

The UCHIKAWA is extremely polluted due to the postponement of the construction of countermeasures in the form of sewage systems in the basin that the WAKAYAMA Municipal office had planned. The River WAKA especially has reached the stage of pollution loads far beyond the capacity of natural purification in spite of enacted countermeasures including completion of sewage facilities, regulating drainages from factories, improvements of rivers, inducing seawater or water from the River KINO, and so forth.

Fig. 2 shows the improvement plan of the River WAKA and Fig. 3 the river's BOD values.

Fig. 3 shows that the river is still very much polluted, although the countermeasures have gradually reduced BOD values to 55 ppm in 1979 from an average of 536 ppm in 1972.

The WAKAYAMA Municipal office budget for sewage improvement is 6 billion yen per year, and its first plan is to be realized in 1985.

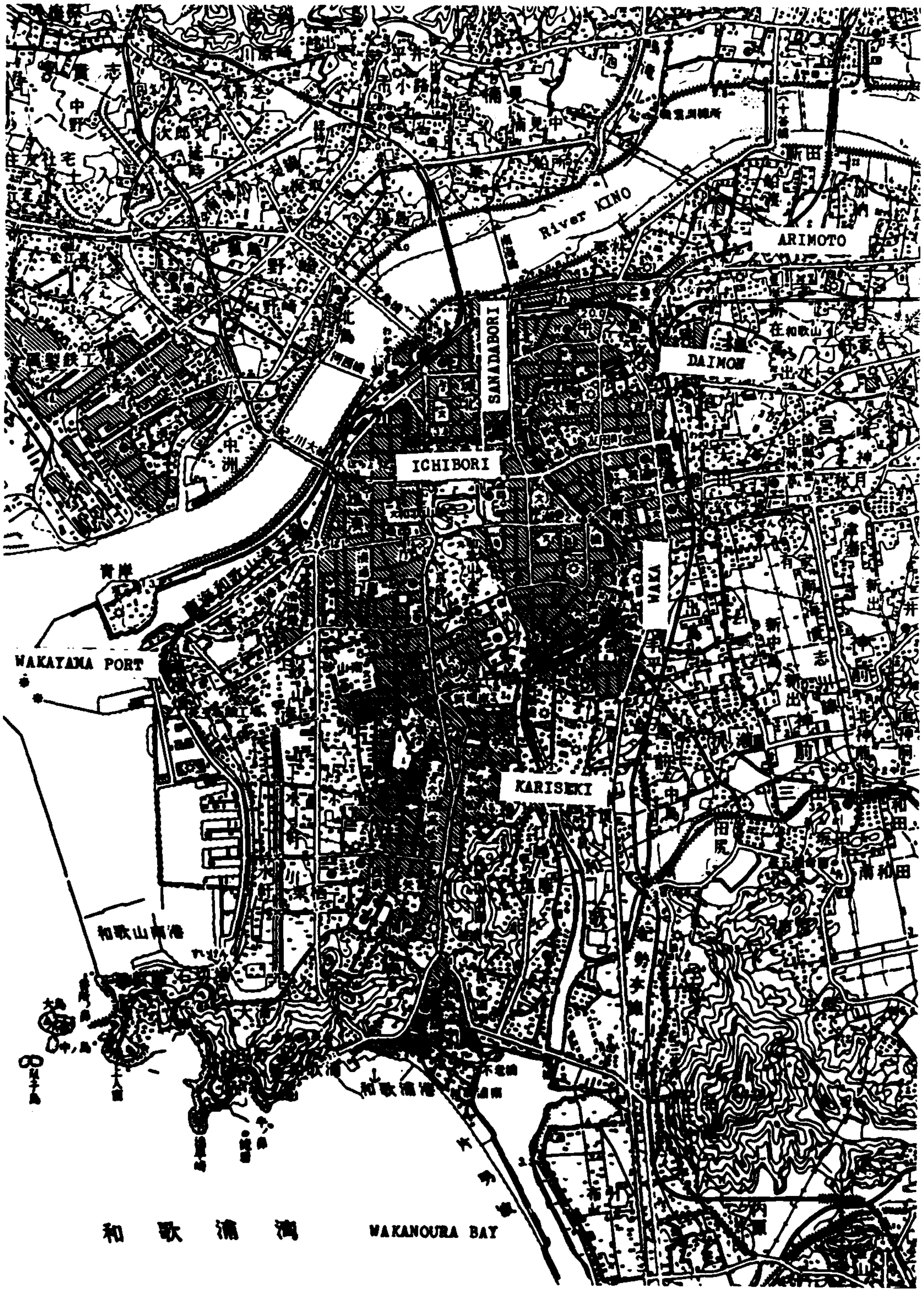

Fig. 1 Location of the UCHIKAWA

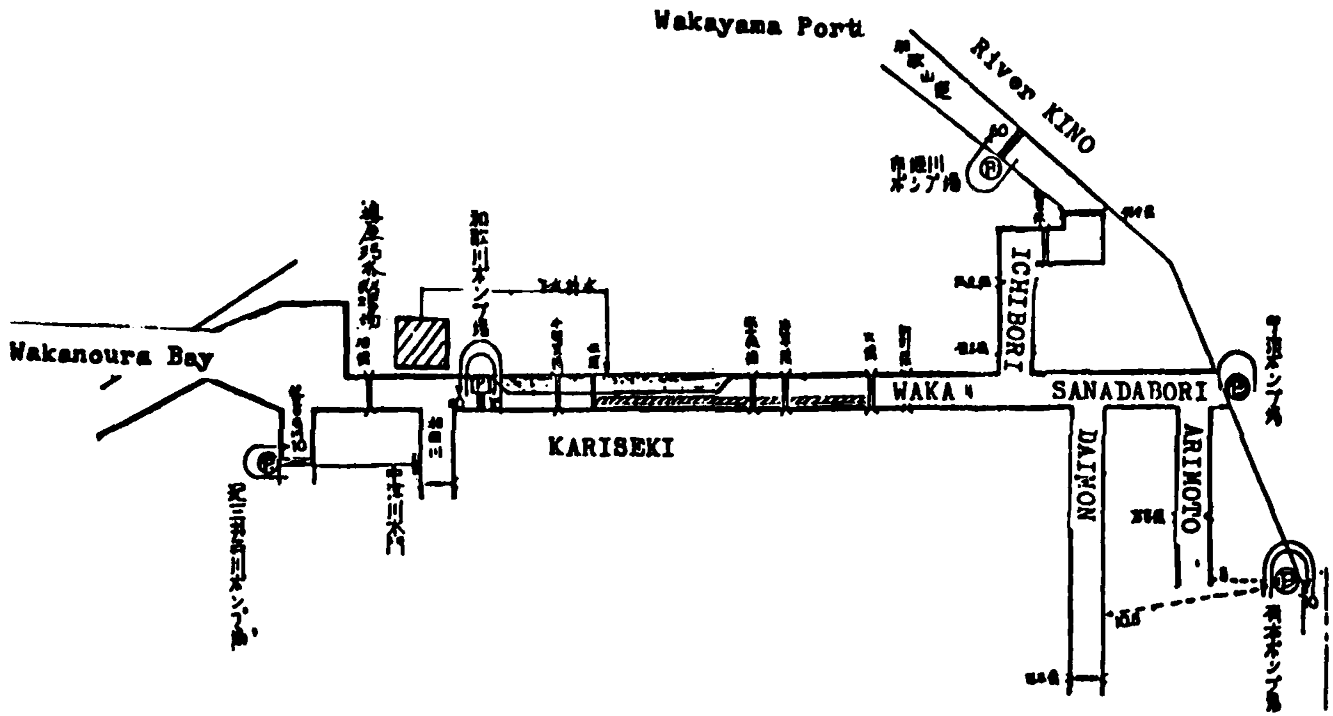

Fig. 2 The improvement plan of the River WAKA

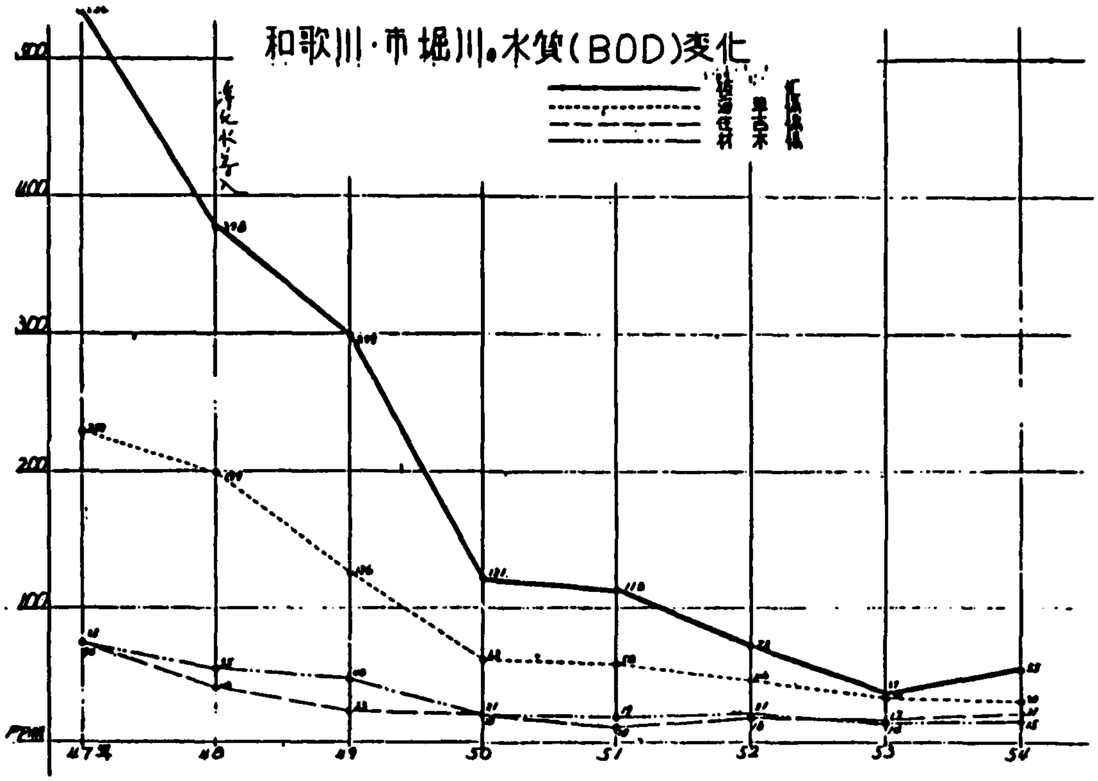

Fig. 3 River WAKA BOD values

We can expect some cleaning of the water of the River WAKA from the sewage improvement, thanks particularly to the realization of this first plan.

The problem, however, lies with the treatment and disposal of bottom sediments over the past many years.

This paper presents the investigations and results concerning this problem.

2. The status of bottom sediments in the River WAKA

To avoid the further pollution of the River WAKA, main river of the UCHIKAWA, the following projects were carried out:

(i) Damed the KARISEKI at a point downstream to interrupt water flowing into the Bay WAKAURA.

(ii) Dredged bottom sediment in the upstream area just against KARISEKI.

(iii) Induced seawater for cleaning and diluting.

In addition we pumped water from the River KINO to other rivers of the UCHIKAWA for the purpose of cleaning those waters.

Although water quality of the UCHIKAWA has improved to some degree, as far as the River WAKA is concerned, the accumulation of bottom sediment has still been progressing and has almost reached the level of the riverbed prior to an earlier dredging.

The causes are likely:

(i) Some amount of sewage has been discharged that was not treated satisfactorily since sewage disposal facilities were not accomplished in part.

(ii) A certain amount of home sewage has been discharged untreated since sewage ducts from homes to sewage disposal facilities have not been constructed yet.

(iii) Drainage from some factories and plants has been discharged either untreated, or without being sufficiently treated.

(iv) Refuse has been thrown directly into the rivers.

Fig. 4 shows one example of the status of bottom sediment in the River WAKA.

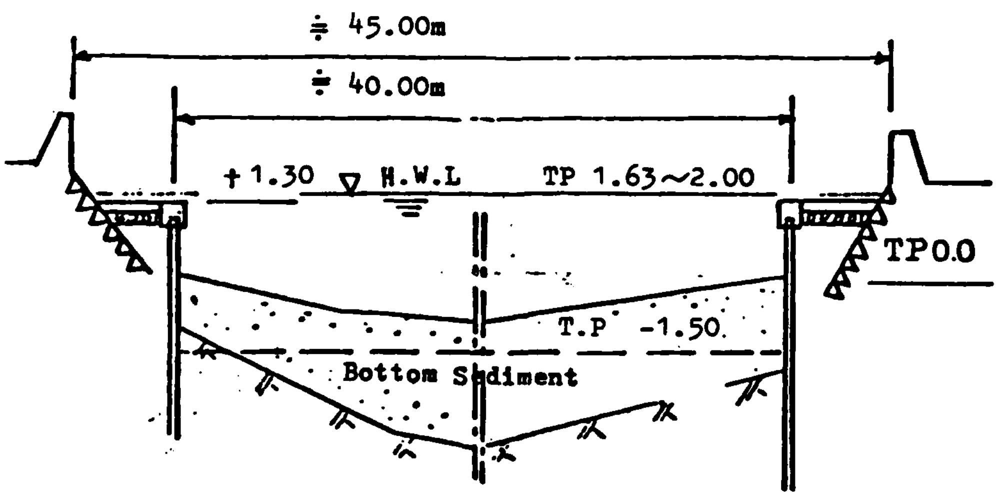

Fig. 4 The status of bottom sediment in the River WAKA

3. Qualities of bottom sediment

Bottom sediment of the River WAKA:

(i) Contains much water and, therefore, is very fluidlike. (High moisture content)

(ii) Is very difficult to concentrate, filter, and dehydrate because of its colloidal state.

(iii) Contains a considerable amount of harmful heavy metals such as Hg, Cr, Pb, Zn, As, Cd, etc.

(iv) Is too organic.

(v) Smeels like tar or septic matter.

(vi) Exists in an oozing state and is very hard to be sedimentary and to be pressed.

4. Investigation of dredging bottom sediment

1) Dredging up bottom sediment

To date out of a total of 200,000 m^3 of accumulated bottom sediment from the KARISEKI to the neighborhood of OHHASI, approximately 76,700 m^3 has been dredged and used to construct a riverside park.

However, since then bottom sediment has again accumulated and its total amount has reached 400,000 m^3 in UCHIKAWA.

When dredging bottom sediment, restrictions (listed in Table 2) are imposed on the method to be adopted since it is a city river.

The restrictions mentioned in Table 2 naturally did not allow satisfactory results using conventional methods such as a grab bucket.

In order to comply with the restrictions we should:

(i) Coagulate bottom sediment before dredging by pouring chemicals and then dredging. This prevents flowing away and diffusing bottom sediment, which means we can dredge without any leakage and oozing.

(ii) Dehydrate and reduce its bulk as much as possible in order to meet restrictions on reclaimed land, reduce transportation cost, and prevent secondary environmental pollution on transportation paths.

(iii) Improve the nature of the soil by dehydrating and make it available for land reclamation.

(iv) Prevent secondary environmental pollution by chemicals used.

The SIL-B treatment method is compared with cement treatment and lime treatment in Table 3.

2) Investigation of treatment process

The following steps comprise the treatment process (also see Fig. 5):

(i) Pretreatment
Removal of bulky refuse over and on river bed.

(ii) Preparation of chemicals
Preparation of activated silicic solution and other chemicals.

(iii) Coagulating bottom sediment
Pouring SIL-B agent and mixing it with bottom sediment and then coagulating.

(iv) Dredging and dehydrating
Dredging; removal of gravels, grits, and refuse; dehydrating by compression; and removal of dehydrated bottom sediment.

(v) Drainage treatment
Treatment of drainage discharged from every subsystem.

5. Treatment experiment of bottom sediment in the River WAKA

A small-scale experiment was conducted using the SIL-B treatment method to confirm its adaptability to the conditions in the River WAKA.

This experiment was conducted mainly by the "A"-method. Parts that could not be done by the "A"-method were done by the "B"-method. Both methods are explained below:

1) The concept of "A"-method is as follows (see also Fig. 6):

(i) Lower the bottomless frame box to the riverbed and then pump the surface water out of the frame box.

(ii) Pour the SIL-B agent into the frame box and mix it with bottom sediment by utilizing a grab bucket.

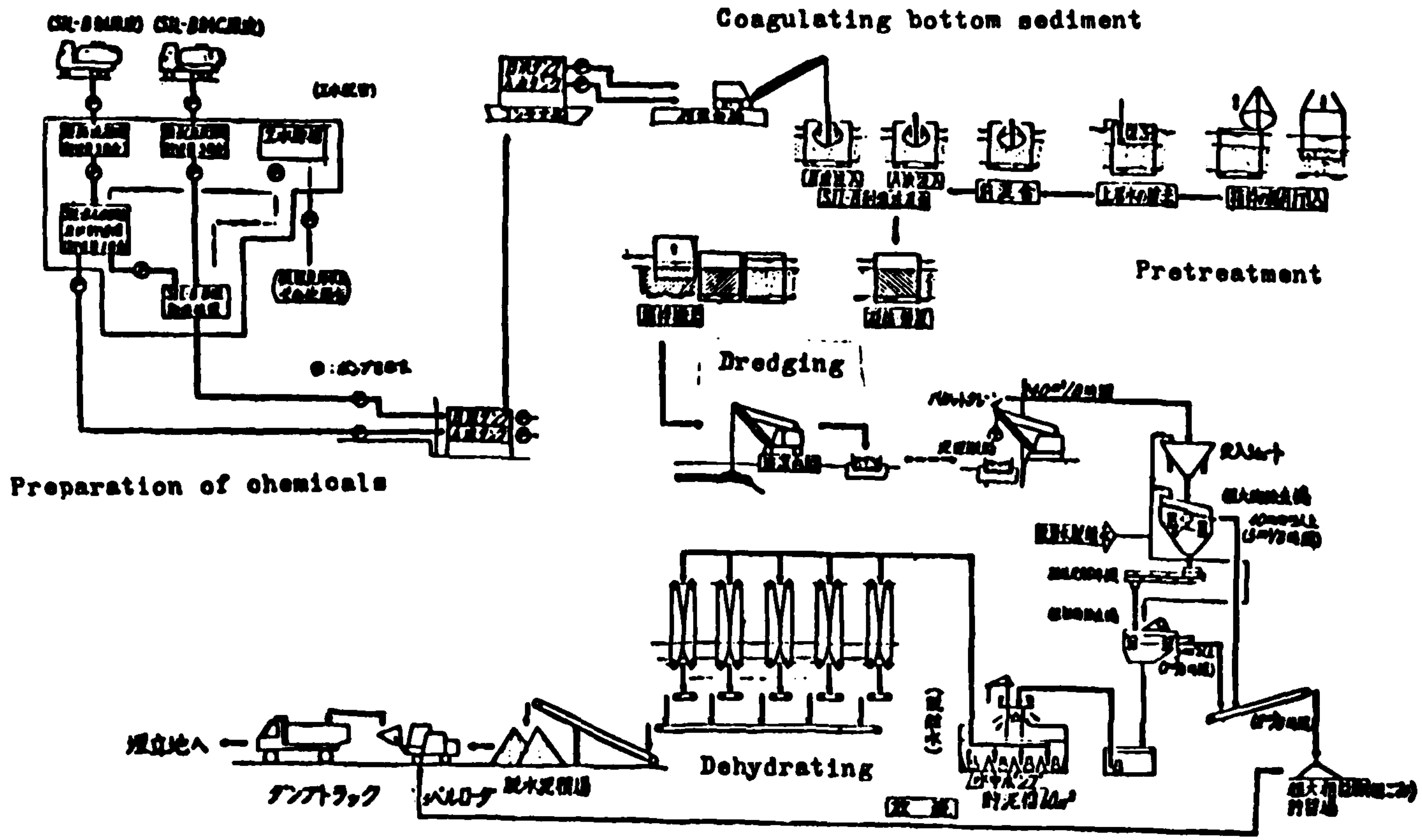

Fig. 5 Schematic Flow Sheet of SIL-B Treatment

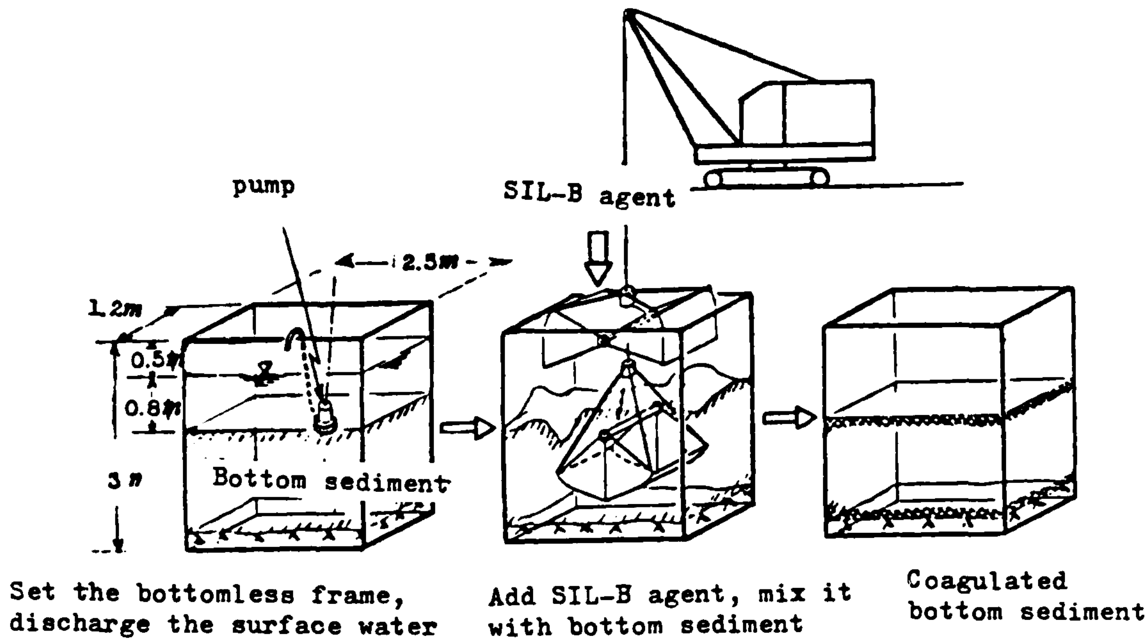

Fig. 6 The concept of "A"-method

(iii) Allow the mixed sediment to coagulate after pouring and mixing with the SIL-B agent.

(iv) Dredge up the coagulated bottom sediment inside the frame box with a grab bucket and dehydrate it with a dehydrating machine to produce the product cake.

2) The concept of "B"-method is as follows (see also Fig. 7):

(i) Dredge up bottom sediment, for example, by grab bucket.

(ii) Place bottom sediment into mixer and pour SIL-B agent into it while mixing.

(iii) Discharge bottom sediment into coagulating tank after mixing and let it coagulate.

(iv) Dehydrate by using a dehydrating machine to produce the product cake.

6. Summary of experiment results

1) "A"-method

(i) It took about 15 min for 5 m^3 of bottom sediment to coagulate. We could confirm that it was possible to use

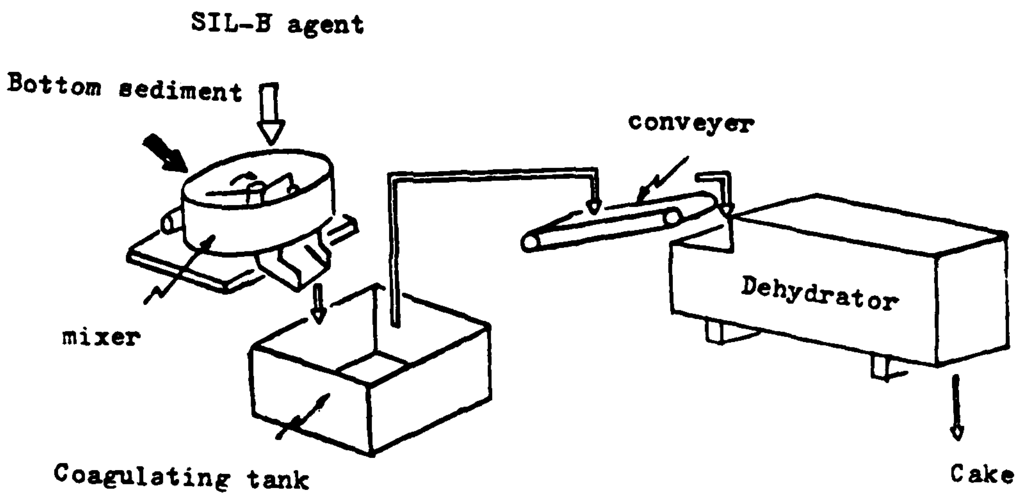

Fig. 7 The concept of "B"-method

the "A"-method to coagulate the riverbed bottom sediment in situ.

(ii) River water penetrating into the frame box from the outside did not destroy the gelling after coagulating, even if the water was on top of the coagulated bottom sediment.

(iii) When comparing bottom sediment not treated by the SIL-B process with sediment that was treated, smells, diffusion of bottom sediment, and turbidity were noticed in the untreated sediment while very little were noticed in the treated sediment.

(iv) Twenty hours after removing only the frame box, the state of the coagulated bottom sediment remaining on the riverbed was checked. It still remained as coagulated on the original spot without any oozing at all.

2) "B"-method

We could obtain good results as well.

3) Properties of bottom sediment treated by SIL-B process:

(i) The product cake contained 62.6% water. The original bottom sediment contained 89.8% water. The dehydrating machine was the squeezing belt press type. Compression was

2, 4, and 8 kg/cm^2 of three-step pressure. Cycle time of compressing was 50 seconds.

(ii) The product cake was neutral and suitable for land reclaiming.

4) Test results for the nature of soil

Table 4 shows the test result of the product cake and Fig. 8 shows the relationship between cone index and moisture content ratio.

(i) The product cake of bottom sediment treated by the SIL-B process had a lower plasticity index and a greater coefficient of permeability than that of the untreated sediment. The nature of the soil was improved.

(ii) The cone index could be raised by dehydrating, and the sediment could be utilized as reclaimed soil.

7. The prospect

It was confirmed that the SIL-B process:

1) Is a neutral treatment that does not cause secondary environmental pollution.
2) Can be reduced in bulk by dehydrating and can be used as good reclaimed soil.
3) Can prevent leaching of harmful substances and can meet regulation values for reclaiming.

In the near future we plan to prove the certainty of the process and to measure the real cost both of materials and labors per operation in the process.

We are presently developing a SIL-B treatment plant pontoon system for use in both the sea and lakes.

8. Summary

We have reported herein the SIL-B process that was used in treating and dredging (in the reverse order in cases of the "B"-method) bottom sediment in the River WAKA to maintain the uses of the River and to prevent environmental pollution.

The SIL-B process has such features as being treated in a neutral

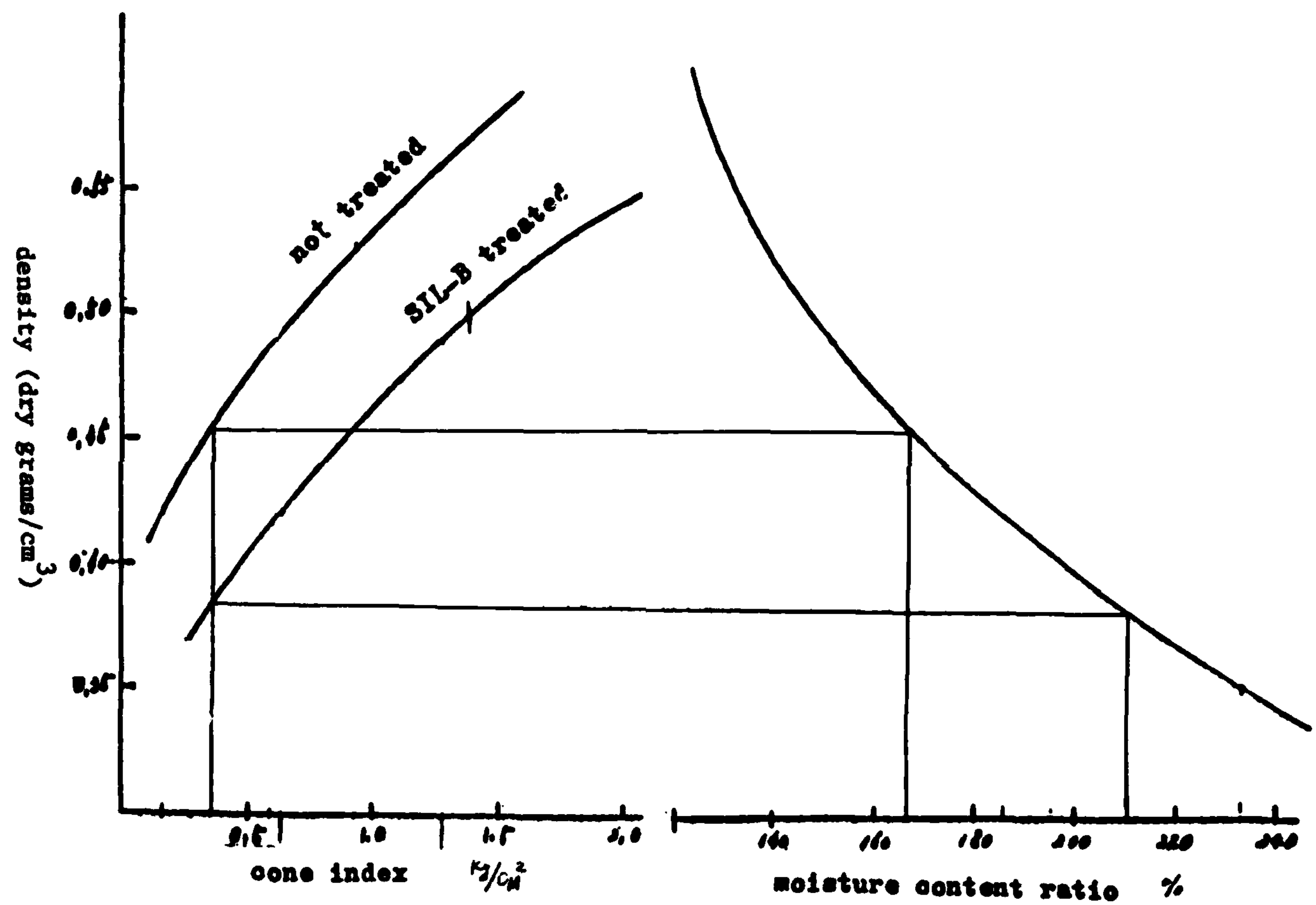

Fig. 8 The relationship between cone index and moisture content ratio

state, being able to reduce the bulk, and causing no secondary environmental pollution.

The causes of the pollution of the River WAKA are considered to be insufficient treatment of sewage; therefore, we are making every effort to complete sewage disposal facilities in our city.

With the completion of this facility, as well as the dredging of bottom sediment in rivers, we expect clean water in our rivers.

All the people of WAKAYAMA city have ardent wishes for clean rivers that they had been proud of.

Table 1 UCHIKAWA Basic Characteristics

Name of river	Length (Km)	Basin area ($10^3 m^2$)	Population (10^3)	Number of factories				
				Chemical	Leather	Dyeing, Textile	Sawing	Others
Waka	7.71	2,500	46.4	27	74	6	19	2
Daimon	4.00	21,600	14.1	2	0	16	9	3
Ichibori	1.60	1,100	12.9	0	0	0	0	0
Sanadabori	1.07	} 2,500	7.3	1	0	3	0	0
Arimoto	1.36			3	0	6	0	1
Total	15.74	27,700	80.7	33	74	31	28	6

Table 2 Restriction in Dredging a City River

Item	Conditions	Requirements
Regional	Residential section	Protection against diffusion of oozing and offensive smell Prevention against noise No space on land to operate
	Transportation	Protection of the secondary environmental pollution on route
	Function of city river	Functional as usual
Nature of bottom sediment	Oozy status	Dredging as high a concentration as possible
	Leaving bottom sediment under the projected line when dredging up	Protection against re-oozing
Operation		Nonharmful and neutral treatment
	Dredging	Almost no secondary envionmental pollution
	Treatment	Utilization as good reclaimed soil
	Disposition	Reduction of bulk Protection against leaching of harmful substance at reclaimed ground

Table 3 Comparison of Bottom Sediment (B.S.) Treatment Methods

Agent	SIL-B	Cement	Lime
Outline of Treatment Flow	Adding agent into B.S. and mixing with each other. Coagulating (Gelling). Dredging. Dehydrating.	Adding cement (milk or powder) into B.S. and mixing with each other. Curing (Solidifying). Dredging.	Mixing lime powder with B.S. Solidifying. Dredging.
Workability	As agent is liquid, mixing operation is easy. Coagulated substance is easily dredged as it is gel, and does not dissolve when submerged.	Because of adding agent of powder or heavy slurry, it is somewhat difficult to mix cement in sludge. It needs a long curing time to obtain compression strength.	Agent is powder, so it is difficult to treat it and to mix it uniformly with B.S. It cannot be submerged because solidified substance returns to sludge.
Effect on Environment	Operating water area is of neutrality. No leach of metal from treated B.S.	Operating water area becomes alkaline. There is some possibility of metal leaching of B.S. in an alkaline condition.	Operating water area is strongly alkaline. There is some possibility of metal leaching of B.S. by alkalinity.
Properties of Dredged Sludge	By dehydration, B.S. reduces volume to about 1/2 of its original one and becomes neutralized soil.	No reduction of volume. Soil is alkaline.	Soil increases in volume and is strong alkaline. A lot of agent is necessary to obtain compression strength.
Appreciation	It is capable of planning operation-methods most suitable to the state of the River Waka. Although dehydration is necessary, treated B.S. changes to good reclaimable soil by dehydration.	A lot of cement is necessary to treat B.S. of the River Waka which contains a lot of organic substances. Due to necessity of long-term curing, alkaline pollution, and no volume reduction, cement is unsuitable.	Returning to sludge by submergence has no adaptability to treating the present B.S. of the River Waka. Moreover, alkaline pollution causes secondary public nuisances.

Table 4 Test Results of Soil

			Bottom sediment	Product cake
Texture	Gravel	(2000μ over) %	2.5	3.5
	Sand	(74 ~ 2000 μ) %	26.5	14.0
	Silt	(5 ~ 74μ) %	28.0	54.5
	Clay	(5μ under) %	43.0	28.0
	Liquid limit W_L	%	251.0	209.4
	Plastic limit W_p	%	73.6	55.3
	Plasticity Index I_p		177.4	154.1
	Classification		clay(organic)	clay(organic)
Specific gravity G_s			2.127	2.485
Moisture content ratio W		%	599.7	160.4
Coefficient of permeability K_{15} (cm/s)			6.2×10^{-6} 9.45×10^{-7}	7.87×10^{-5} 1.31×10^{-6}

ON THE NEW METHOD OF TREATING BOTTOM SEDIMENT BY A SILICIC COAGULANT (SIL-B TREATMENT METHOD)

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1. Outline

The method of treating bottom sediment and sludge by a silicic coagulant is called the "SIL-B treatment method." The SILICA BONDING METHOD is shortened to the SIL-B method. Much of the bottom sediment that accumulates in rivers, lakes, marshes, and sea areas contains nutrients, harmful materials, etc., since drainage from sewage treatment plants, industrial sewage, and domestic sewage flows into them.

Therefore, from the point of view of purification and preservation of the environment, its treatment and disposal are of great importance.

In our country, many and various kinds of counterplans have been considered, but no complete method of treatment has yet been worked out.

This fact is very clear in terms of the physical and chemical properties of bottom sediment.

(A) The moisture content, colloidal corpuscular composition, and hydrophilic properties of the bottom sediments are such that its resulting filtration and dehydration properties are poor.

(B) Since the kind of bottom sediment is diversified, no complete countermeasure is available with only one method of treatment. For example, bottom sediments contain inorganic and organic substances, their mixture, nutrients, harmful materials, PCBs, cyanogen, oil, etc.

(C) Most of the bottom sediment is high in mobility and has an oozy state. Therefore, it is very difficult to avoid the diffusion of harmful materials in water in case of dredging and removal.

It is especially difficult in the grab bucket method, since leakage results during hoisting.

(D) Treatment cannot be considered independently of subsequent disposal.

In disposal of bottom sediments containing harmful materials, the harmful materials must be absolutely prevented from flowing into groundwater aquifers.

Even if dehydrated cakes of dredged material are disposed of at sea, it must be regarded as a possible source of secondary pollution should the dehydrated cake liquify to sludge due to increasing moisture.

In this sense, it is desirable that the physical and chemical properties of a treated substance are stable in case of treating harmful bottom sediment.

As mentioned above, it is clear that the research and development of the treatment method is difficult, depending on the kind and property of bottom sediment.

We have overcome many of the conditions that make it difficult to treat harmful materials. For inorganic materials that are harmless to the environment we have

(A) improved the dehydration,

(B) secured the physical and chemical stability of a dehydrated cake and a dry substance, and yet prevented secondary pollution in disposal,

(C) considered recycling of the final treated substances.

Such being the progress, we have developed a new method

of treatment by using a silicic coagulant (SIL-B treatment method) with the aid of Osaka Municipal Institute of Technology. This method is explained below.

One object of this research is to avoid using an organic polymer which may be poisonous to fish due to the residual monomer and owing to the solid-liquid separation in cases of treating highly hydrous bottom sediment and sludge.

Another object is to avoid secondary pollution due to strong alkalinity such as lime, cement, etc.

2. What is the SIL-B treatment method?

As mentioned above, a silicic coagulant is employed as a binder of bottom sediment in the SIL-B treatment method.

The silicic coagulant contains sodium silicate as a main agent. When such an acidic substance as sulfuric acid is added to it for neutralization, a new active chemical substance, siloxy-silanol or siloxane, is produced. Siloxane is an aqueous solution with very little viscosity that has a good mixing property with bottom sediment.

Siloxane gells within a short time when within a certain pH range (Fig. 1).

When a proper amount of siloxane is mixed with bottom sediment and sludge by adjusting the pH value to a range of 7 - 7.5, highly hydrous bottom sediment and sludge gel in the state of containing moisture. This is called hydrogel.

Hydrogel loses the inconvenient mobility and cohesive power of highly hydrous bottom sediment and sludge, becomes plastic, produces a bearing power (though it is weak), and obtains compressibility. Thus, dehydration

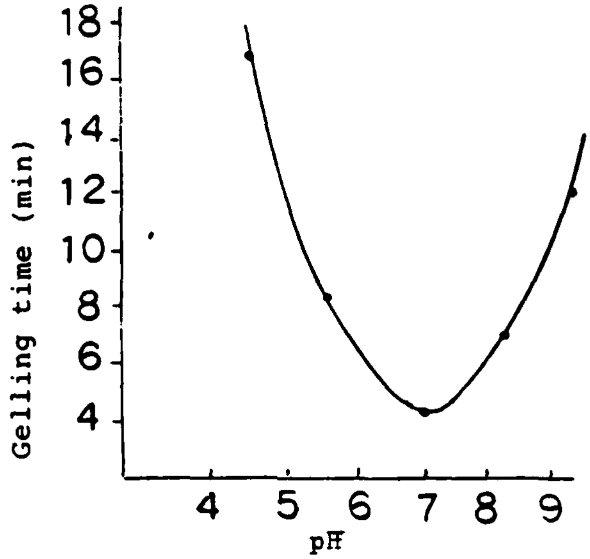


Fig. 1 pH and gelling time of siloxane

as a result of pressure is greatly improved (Table 1).

A comparison of the result of an application of pressure for 15 min. with that for 120 min. tells us that the effect of improving the dehydration by the SIL-B treatment method is excellent and efficient.

Next, let us look at Table 2 to notice the excellent effect of drying (in the sun and by wind) of a SIL-B-treated cake.

A dehydrated cake oozes out moisture more or less by a syneresis reaction to be dried quickly.

Table 3 shows the relation between the SIL-B-treatment and re-leaching of harmful substances which are contained in bottom sediment.

3. Recycling and effective utilization of SIL-B-treated substances

The main subject of the present report, namely, the SIL-B treatment of harmful bottom sediment in rivers,

means that silicic acid, which is the principal component of sand, is employed as a binder for colloidal and corpuscular bottom sediment. It follows that the physical property of the final treated substance (dry substance) is greatly improved.

(A) The coefficient of water permeability greatly increases.
(Example) Initial sludge $10^{-8} \rightarrow 10^{-5}$

(B) The index of plasticity (I_p) decreases.
(Example) Initial sludge $30 \rightarrow 8$

(C) The water resisting quality increases and no decay occurs during long-term soaking in water.

(D) The CBR value increases.
(Example) The CBR value of service water treated sludge increases by more than 20%.

Thus, it can be said that there are some possible factors for recycling resources and effective utilization.

For example, it can be utilized for embedding, banking, gardening, and reforestation in the field of civil engineering.

Although our present subject is the treatment and disposal of harmful bottom sediment, let us suggest that the SIL-B treatment method can be applied to various kinds of sludge, as shown below:

(A) Inorganic sludge

(B) Sewerage treated sludge

(C) Organic sludge like excess sludge in treating active sludge

(D) Metallic hydroxide sludge, etc.

The outline of the flow in treating these substances is as follows.

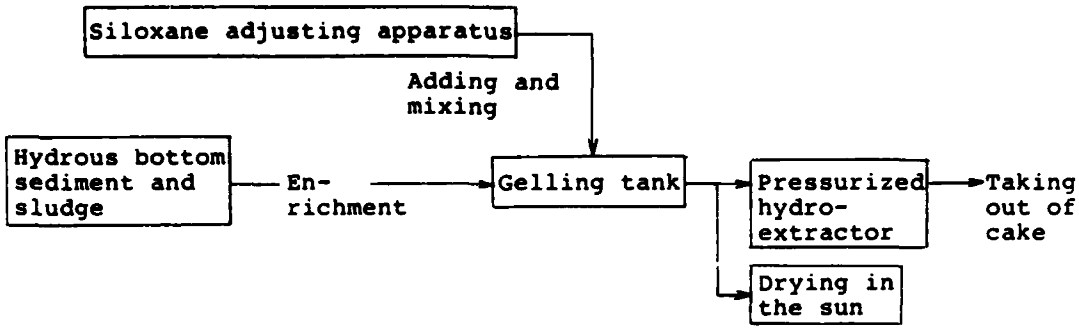


Fig. 2 SIL-B treatment flow

4. Chemical explanation of the SIL-B treating coagulation

The history of the appearance of sodium silicate, the principal element in the SIL-B treatment, is very old.

It is said that it began in the prehistory age, but its chemical structure is not definitely known at present. According to many physical and chemical investigations, the following structure is presumed:

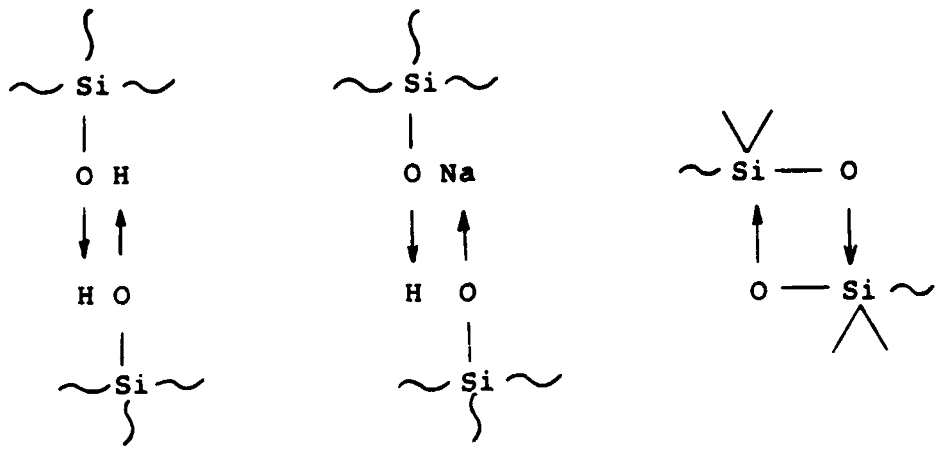
$$\mathrm{NaO} - \underset{\mathrm{OH}}{\overset{\mathrm{OH}}{\mathrm{Si}}} - \mathrm{O} - \Big(- \underset{\mathrm{OH}}{\overset{\mathrm{ONa}}{\mathrm{Si}}} - \mathrm{O} - \Big)_n - \underset{\mathrm{OH}}{\overset{\mathrm{OH}}{\mathrm{Si}}} - \mathrm{ONa}$$

where $n = 1 \sim 3$

In other words, this can be understood as a partial sodium salt of linear siloxy-silanol oligomer.

When sodium silicate is dried and enriched, it becomes three-dimensional and is gelled (coagulated) due to a hydrogen bond stemming from molecular mutual approach and dipole-dipole interaction (Fig. 3).

However, the gel in this case is a reversible gel which can be dissolved by hydration, and is therefore



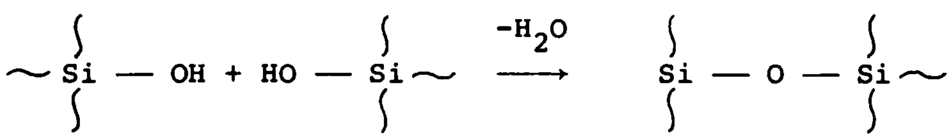
Hydrogen bond

Dipole-dipole interaction

Fig. 3 Example of the gelling mechanism of sodium silicate

considered an apparent gel.

On the other hand, sodium silicate, when neutralized with an acidic substance, produces silicic acid liquid, i.e. siloxy-silanol oligomer. The silanol radical is extremely active, induces silanol polymerization, forms a siloxane bond, and gels.



Thus, what was once chemically gelled is now an irreversible gel which cannot be dissolved again by hydration.

Mr. Isao Tabuse, a chief of the River Section, Wakayama Prefecture, reports that an irreversible gel which is not dissolved by hydration in the above-mentioned SIL-B treatment is produced. This would be applied to a new idea for dredging and removing bottom sediment in the River Waka.

5. Discussion

The outline of the SIL-B treatment method has been mentioned above as an introduction for the main subject of this paper, removing bottom sediment in the River Waka, in expectation of its being adopted.

(A) In removing oozy and moving bottom sediment, it can be gelled while still on the river bed to make it lose its mobility and to make it plastic.

Thus, it is possible to remove oozy bottom sediment completely by grab bucket dredging.

(B) Dehydration then becomes easy, which is useful for volume reduction.

(C) There is no fear of harmful materials leaching into the disposal area (coastal reclaimed land).

(D) Because of the neutral treatment and harmless inorganic composition, there is no fear of fish poisoning.

Let us conclude this report by saying that we are sure of this novel treating technique.

Table 1 Comparison of pressurized dehydration between SIL-B-treated bottom sediment and PAC-treated bottom sediment

	Application of pressure	Percentage of moisture content in cake	Dehydration
SIL-B treatment	Pressurization 10 min. Compression 5 min.	72%	Good exfoliation Almost no clogging in filter cloth
PAC treatment	Pressurization 10 min. Compression 5 min.	96.7%	Poor exfoliation Remarkable clogging in filter cloth
	Pressurization 60 min. Compression 60 min.	76%	Moderate exfoliation

Sample: Sludge from service water treatment
Initial percentage of moisture content of sludge: 98.9%

Table 2 Drying state of SIL-B-treated cake (at 20°C, indoors)

	Initial % of moisture content of sludge	Immediately after dehydration	After 2 days	After 3 days	After 5 days
% of moisture content	98.9%	72%	63%	47%	33.3%

Sample: Sludge from service water treatment

Table 3 Analysis of syneresis water of SIL-B-treated sludge and leaching test for dry cake

(Unit: ppm)

Sample	Initial content in sludge	Syneresis water	Naturally dried substance	Dried substance heated at 150°C
Total mercury	0.68	ND	ND	ND
Arsenic	12.00	ND	ND	ND
Total Chromium	80.00	ND	ND	ND
Cadmium	1.30	0.02	ND	ND
Zinc	190.00	0.02	ND	ND
Lead	60.00	ND	ND	ND
Nickel	35.00	0.03	ND	0.03
Copper	60.00	ND	ND	ND

ND: Not detectable

Test: Osaka Municipal Institute of Technology

Method: Notification No.13 of the Environment Agency

POLLUTION STUDIES AT TSU-MATSUZAKA HARBOR AND REMOVAL OF SEDIMENT AT ESTUARIES NEAR IT

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Abstract

With the economic progress of our country, the water pollution in Mie Prefecture, especially along the shore of Ise Bay, has worsened year by year. Since the districts near Tsu and Matsuzaka are most densely populated and most active in industries among Mie Prefecture, the water pollution is an important environmental problem. To meet this problem, the prefectural government recently performed pollution studies near the harbor and established a clean-up plan.

This paper deals with the results of the pollution studies and reports how sediment removal was carried out as scheduled for the 1st year of the total plan, and how the dredged material was managed.

1. Background of Ise Bay

Ise Prefecture extends north and south east of the Suzuka Mountains. The plain districts, along the shore of Ise Bay, are the most densely populated (Fig. 1). 1960 has brought about a better standard of living, but has also created a problem in the environment.

Among the various environmental problems, water pollution has had a most significant influence on our life, because it diverses and propagates in a vast sea area.

Although polluted rivers and seas have the potential to purify themselves by dilution, precipitation, and decomposition of pollutants, if they are polluted beyond their self-purifying ability, eutrophication of seawater may result, causing an outbreak of red tides.

Therefore, in Mie Prefecture, constant efforts have been directed to restrict inflowing effluents according to the Water Pollution Prevention Law. As a result, water quality in open seawater has considerably

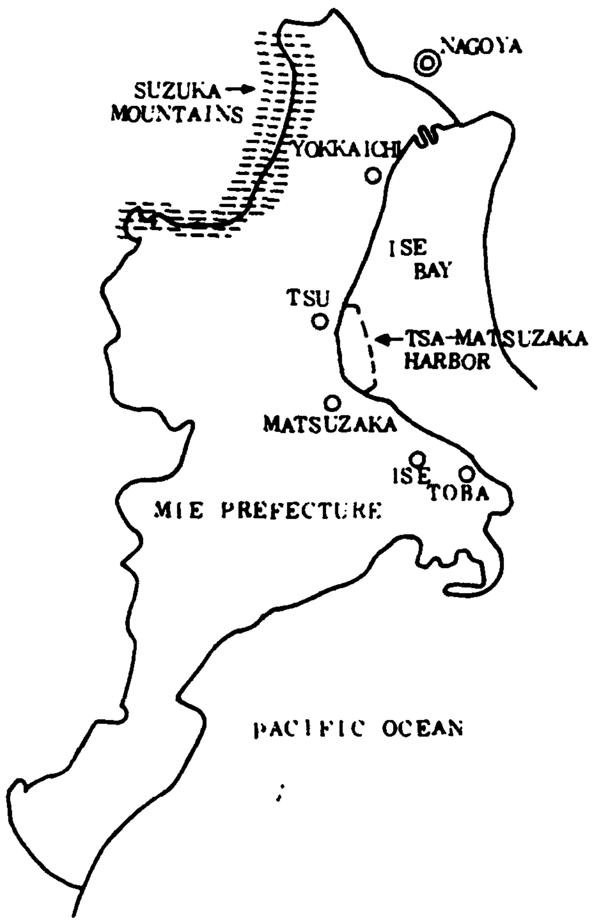


Fig. 1 Situation of Mie Prefecture

improved. However, in closed water areas such as inside a Bay, the number of red tides increases year by year (Fig. 2).

Therefore, the prefectural governments were urged to establish a comprehensive measure for seawater restoration.

In June 1978, a gross weight system of water quality was introduced, which had a completion goal for 1984, aimed at restricting the inflowing quantities of pollutants systematically and effectively, making all pollutants including urban drainage and industrial effluents an object of restoration. Furthermore, water quality monitoring apparatuses are located at major points and effective observation by telemeter is being performed.

There are 41 main rivers which flow into Ise Bay. Twenty-three

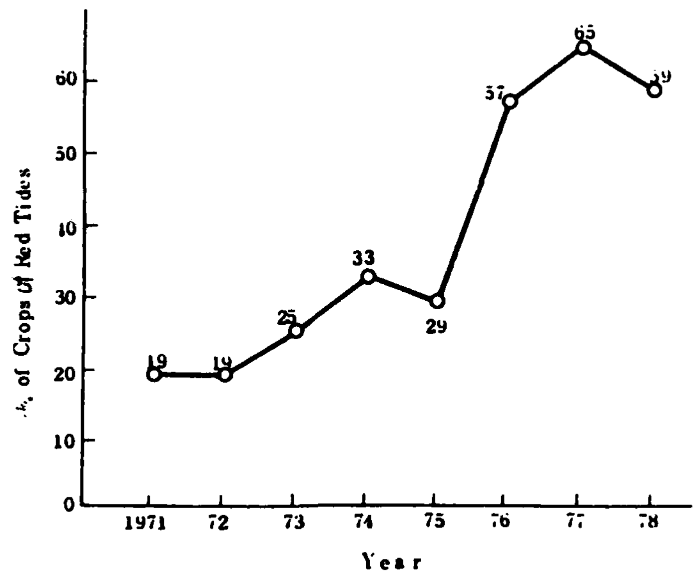


Fig. 2 No. of Crops of Red Tides

of these are granted a group ranking, which creates an obligation to protect their environment and to utilize water according to their conditions. The conditions of these rivers are summarized in Table 1. Table 1 shows a general tendency toward improvement for most rivers, but there are still unimproved rivers resulting from urban drainage caused by increased population. The concentrations of COD of seawater are shown in Table 2.

2. Pollution Studies of the Rivers Shitomo and Iwata

Since the pollution of seawater advanced along the shore of Ise Bay, it became an important environmental problem.

Especially in estuaries it caused bad smells and created red tides. It resulted in a decrease in marine products and in a decline in the sightseeing industries, a great economic resource.

To solve this problem, pollution studies were carried out in 1978 and in 1979 at the Tsu district, which is most densely polluted near Matsuzaka Harbor.

At the Tsu district 4 rivers (Shitomo, Ano, Iwata, and Aikawa) flow into the sea area of Tsu-Matsuzaka Harbor; among them River Shitomo is the largest (Fig. 3).

The sediment in the estuaries of River Shitomo is black and has the strong smell of hydrogen sulfide. It is also anaerobic, because its

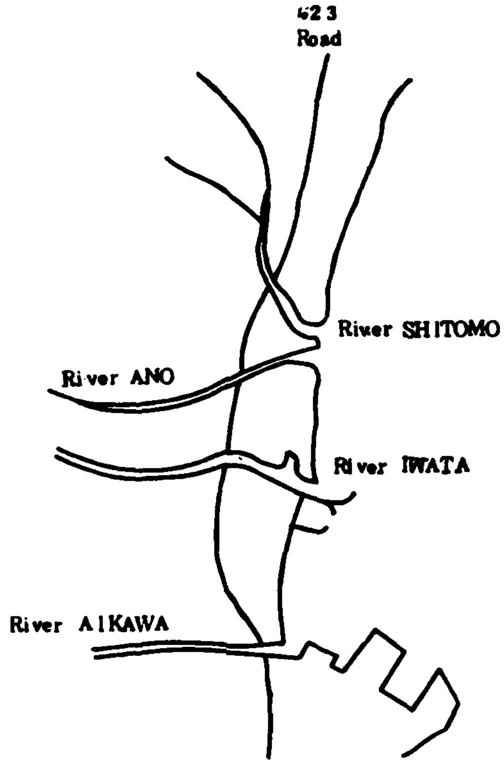


Fig. 3 Main Rivers near Harbor

value of oxidation reduction potential (ORP) is -32.2 mV. Its water content, liquid limit, and plastic limit are 194.1%, 121%, and 43.6%, respectively.

The sizes of the soil particles are: sandy 3.8%, silty 72.1% and clayey 25%. The size distribution is shown in Fig. 4.

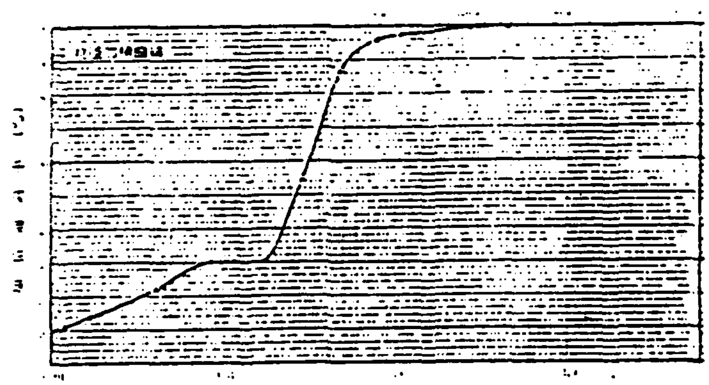


Fig. 4 Size Distribution of Sediment

Regarding the main indexes of pollution, COD_{MN}, ignition loss (I.L.), and sulfide, their vertical distributions in the sediment were examined (Figs. 5-7). As Fig. 5 shows, the concentration of COD_{MN} in the upper layers is large and in deeper layers is small. It approaches some constant value at a depth of 3-4 m. The concentration of COD_{MN} at the point of convergence becomes a background value proper to an unpolluted state, 10 - 20 mg/g.

As to ignition loss, it behaves quite the same as COD_{MN}. Its background value exists also at 3 or 4 m. But as to the concentration of sulfide, it behaves differently from the preceding two indexes. Although it has a large deviation, it has a distinct tendency to vanish at a

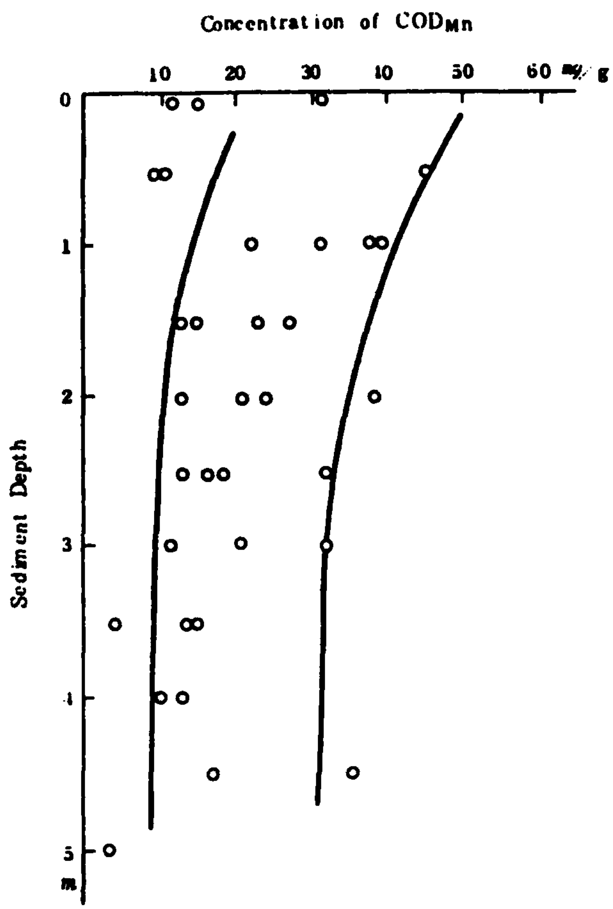


Fig. 5 Vertical Distribution of COD in Sediment

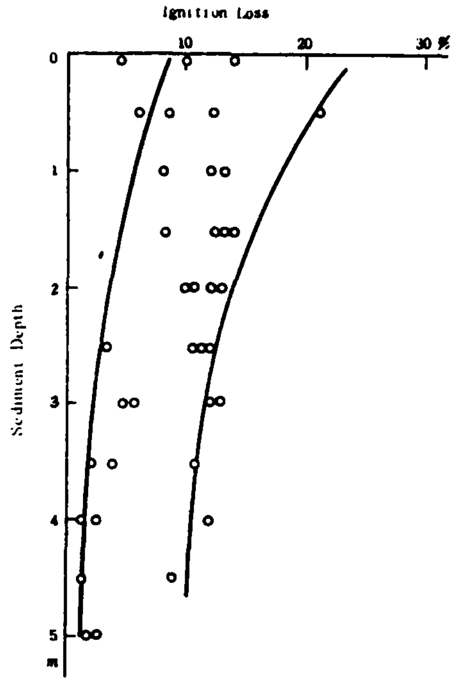


Fig. 6 Vertical Distribution of I.L. in Sediment

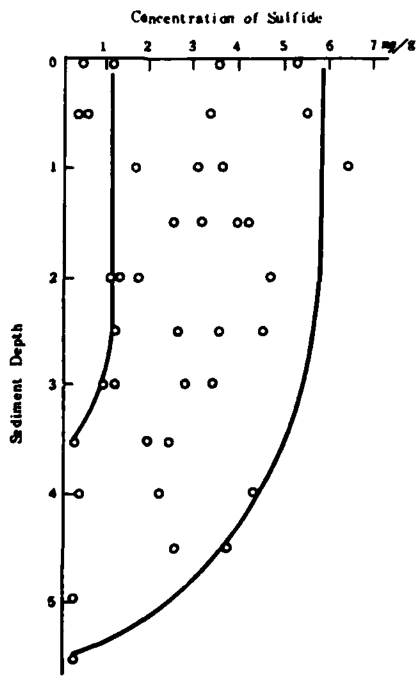


Fig. 7 Vertical Distribution of Sulfide in Sediment

sediment depth of 3.5 - 5.5 m. From these data, we can say that the thickness of accumulated sediment at Shitomo river is 4 - 5 m.

As to the sediment in River Iwata, sediment analyses were performed in the same way as the ones in River Shitomo.

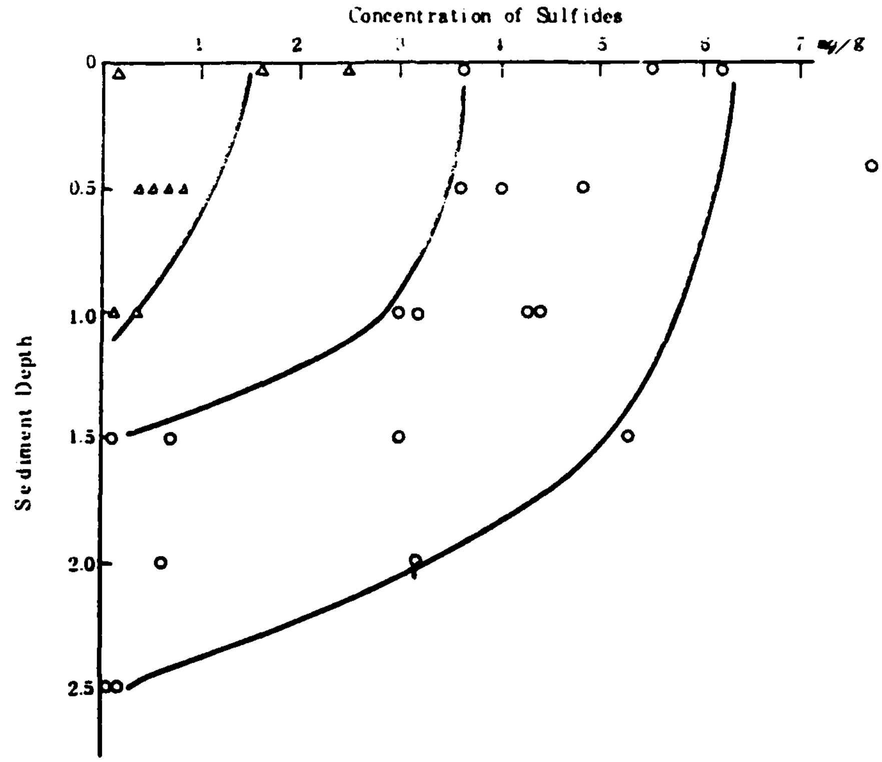


Fig. 8 Vertical Distribution of Sulfides in Sediment

The vertical distribution of sulfide concentrations is shown in Fig. 8 as representative data for River Iwata. From these data it is presumed that the thickness of pollutant accumulation may be 2 - 3 m.

The concentrations of SS in water, measured at Edo bridge, are plotted in Fig. 9. They have a large deviation and change with each year. The extraordinarily high values may be caused by plankton. Their lower values are between 15 - 30 ppm. The seasonal change of DO concentration is indicated in Fig. 10. As the figure shows, the concentration of DO becomes small in the summertime and indicates its maximum in February. Notice that the river water is anoxic to the greatest extent in the summertime. The concentration of BOD is usually 4 - 5 ppm, but in summer there is a higher value than 10 ppm.

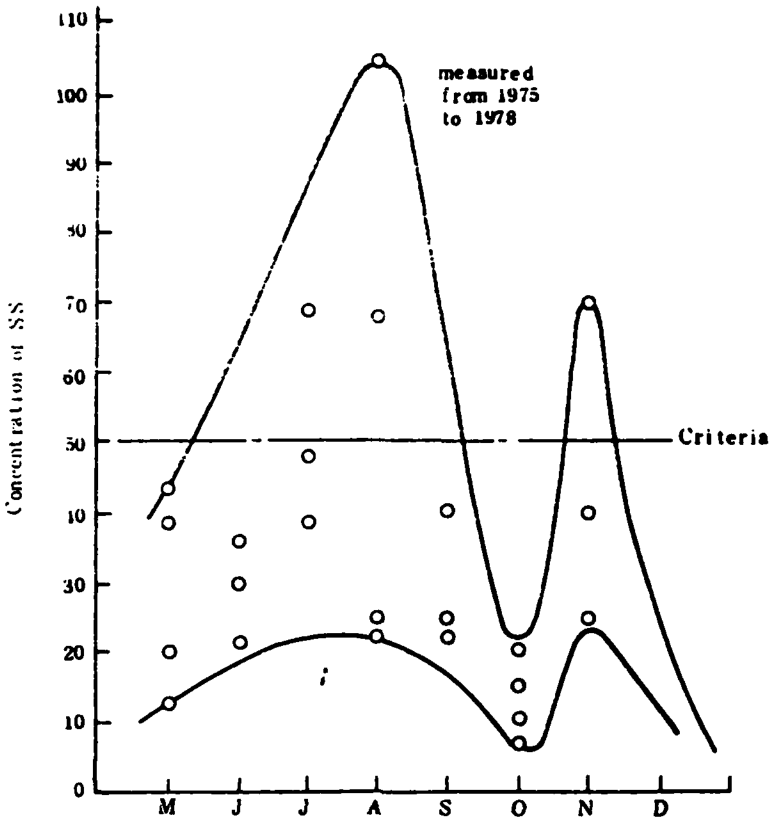


Fig. 9 Concentrations of SS of River Shitomo

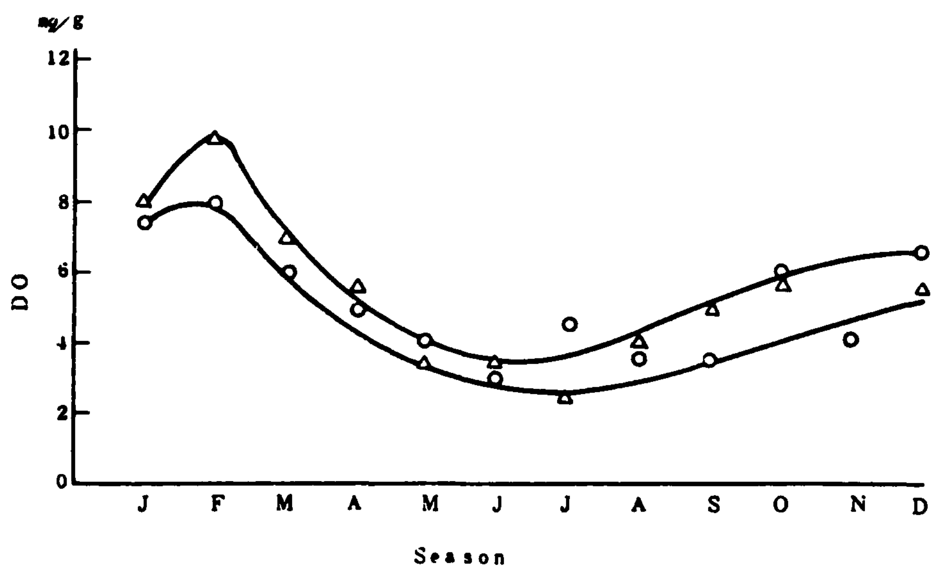


Fig. 10 Seasonal Change of DO Concentrations

The seawater quality in the Harbor is a little better than in the river, but much worse compared to other unpolluted areas.

3. Criteria of Sediment Removal and Dredging Plan

From the vertical distributions in Figure 11 pollution can be regarded as concentrations above the background levels of COD_{MN} = 10 mg/g, I.L. = 5%, and sulfide = 1 mg/g. As the concentration of sulfides is

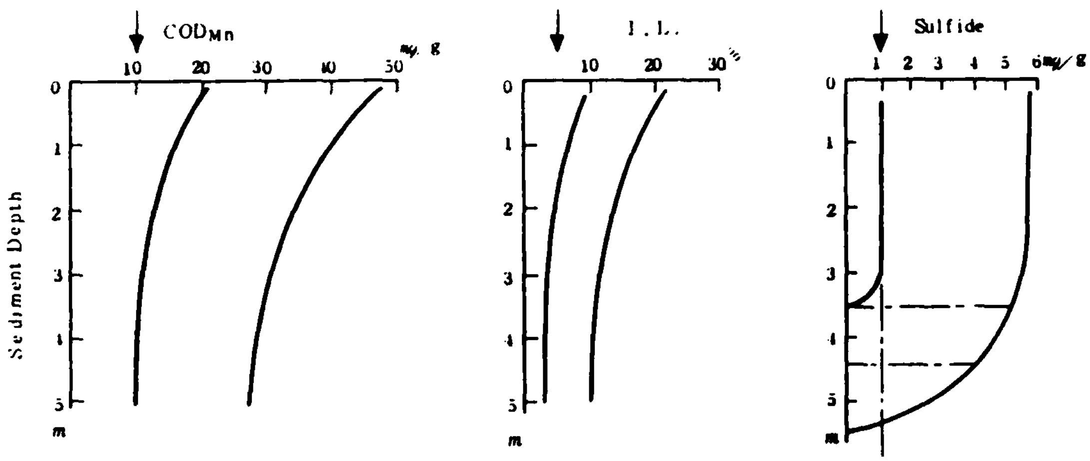


Fig. 11 Vertical Distributions of the Main Three Indexes

the most adequate index for pollution of the three, the criterion for sediment removal is determined as sulfide > 1 mg/g.

According to this criterion, the thickness of sediment to be removed is 3.5 m at the upper part and 4.5 m at the lower part of the stream.

The soil pillar diagrams at Rivers Shitomo and Iwata are indicated in Fig. 12 and Fig. 13.

From these data the total amount of sediment to be removed at Shitomo and Iwata rivers is 551,000 m^3. The dredging plan was scheduled as shown in Table 3.

4. Dredging Performance

According to the 1st year of the schedule, 105,000 m^3 of sediment was dredged from the mouth of Shitomo River until about 900 m from the upper part. The dredging began on 7 June and stopped on 20 Sept. 1980.

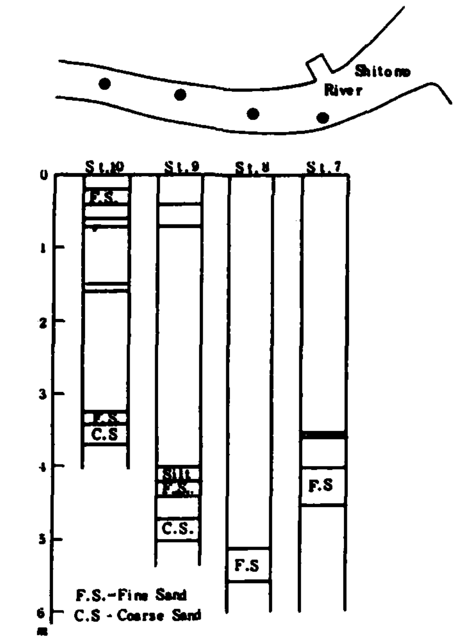


Fig. 12 Soil Pillar Diagram at River Shitomo

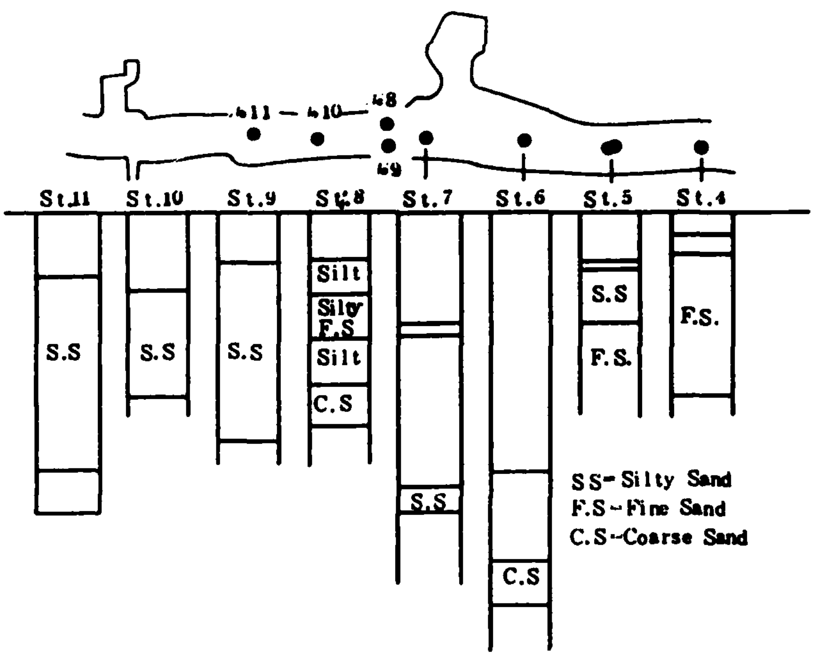


Fig. 13 Soil Pillar Diagram at River Iwata

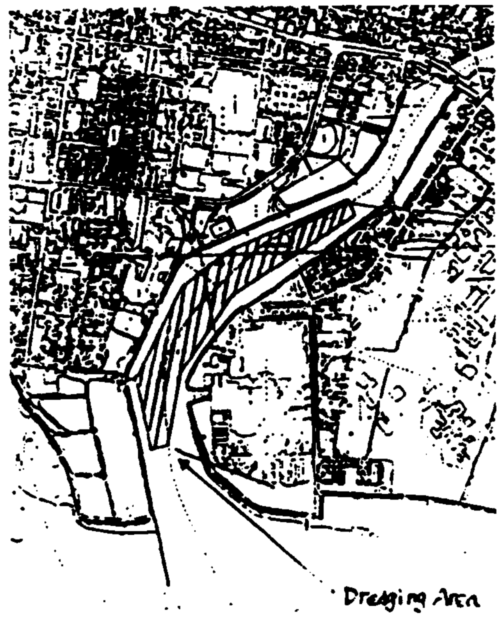
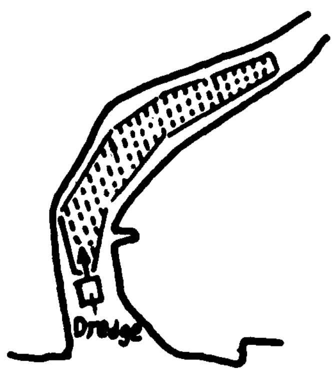


Fig. 14 Dredging Area of Shitomo River

The dredge used was 40 m long by 12 m wide by 3 m deep, with a 1.5-m draught, and had a diesel engine of 1350 HP with a booster pump of 600 HP. The normal cutter-type suction devices were installed in it.

The dredging was performed from the lower stream to the upper.



The dredged materials were conveyed directly by pipe to the deodorizing plant. As the disposal site is very near, the conveying was very simple and easy. The dredging conditions were (1) large depth of removed sediment (3.5 - 4.5 m), (2) big difference between ebb and flow, (3) small distance between dredge and dwelling houses, etc. Corresponding to

these conditions the work was carried out satisfactorily.

The seawater quality at the appointed inspection points was observed during operation, as indicated in Fig. 15. As the figure shows, the impact of the dredging operation upon water quality was comparatively small and caused no problems.

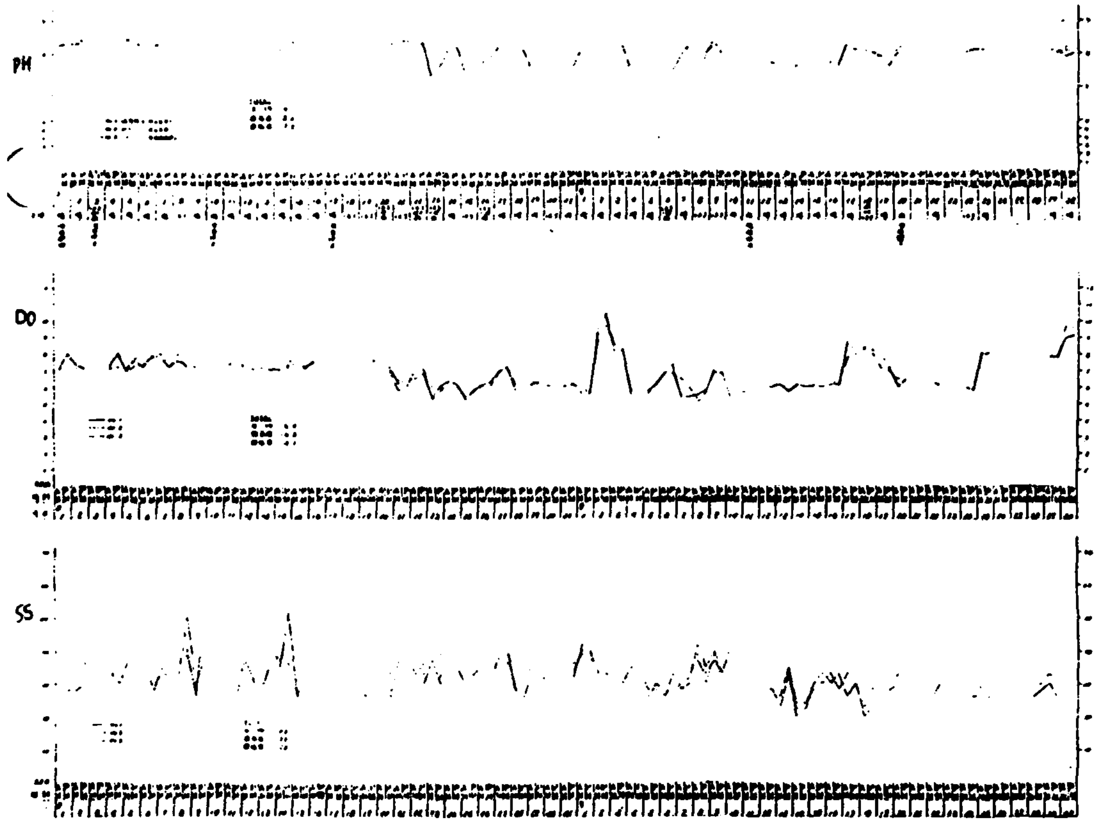


Fig. 15 Inspection of Operation

5. Management of Dredged Materials

The disposal site was chosen at an open space on a beach near the mouth of the river (Fig. 16). The dredged materials were conveyed hydraulically with the help of a booster pump. As a whole the conditions for sediment treating (dredging-transportation-disposal) were advantageous and simple. With respect to management of dredged materials, there was a problem of odor propagation because the water depth was very shallow and dwelling houses were very near the dredging site. Therefore,

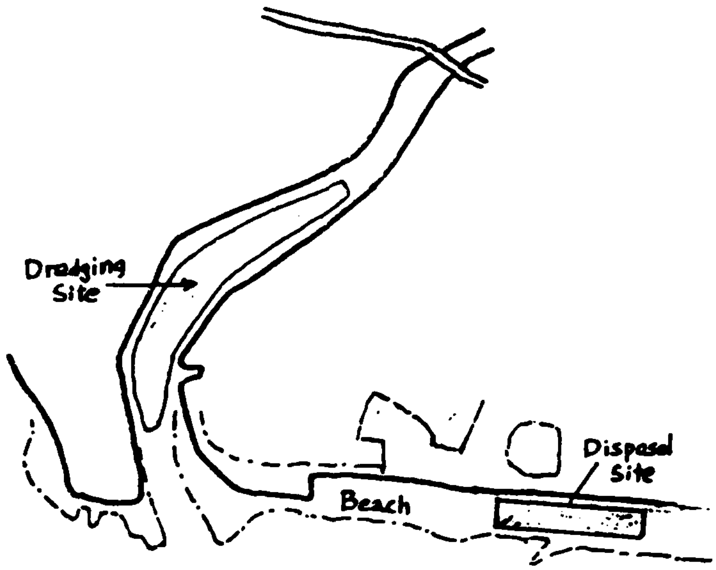


Fig. 16 Dredging and Disposal Sites

emphasis was placed on measures to monitor bad odors caused by dredged materials.

5-1. Deodorization

The generation of smells from sediment is regarded as a phenomena caused when gases separate from sediment by the action of bacteria such as sulfate-reducing ones in anoxic conditions, which are created by the decomposition of organic matter in pollutants.

It is known that organic sulfur compounds are produced under the condition of ORP (Oxidation and Reduction Potentials) 0 - -200 mV in sediment. Therefore, to prevent odors it is necessary to lower the absolute value of ORP in the direction of zero, that is, to decrease anaerobic conditions.

To examine this matter, tests on the effects of odorants upon ORP values were performed. In Fig. 17, the relationships between the change of ORP value with time and annexed quantities of iron chlorides are plotted. As the figure shows, in the case without odorants, the value of ORP in sediment has a tendency such that its absolute value increases with time and approaches about $|200|$ mV. When annexing odorants, the values of ORP to be converged dimish considerably. The more annexed

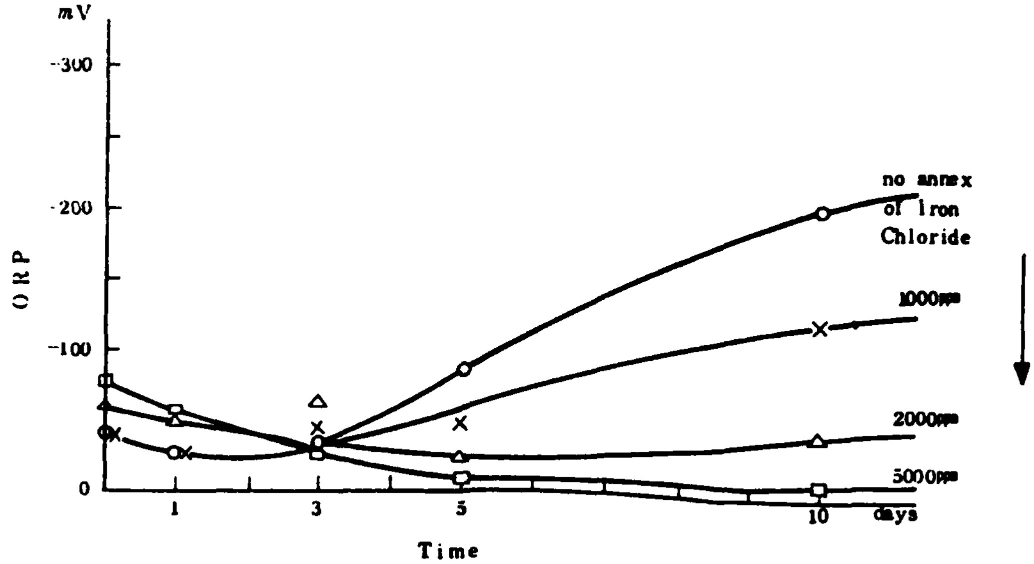


Fig. 17 Relationship between ORP and Annexed Quantities of Deodorants

quantities, the nearer the zero point is approached.

It is well known that the addition of slaked lime to iron chlorides makes the deodorizing action more effective, because, chemically, sulfur compounds react with iron chloride and absorb H_2S gas.

The deodorization plant was located as shown in Fig. 18.

The general view of the slaked milk plant is indicated in Fig. 19. These deodorants were directly poured into the sediment-conveying pipe inside the plant.

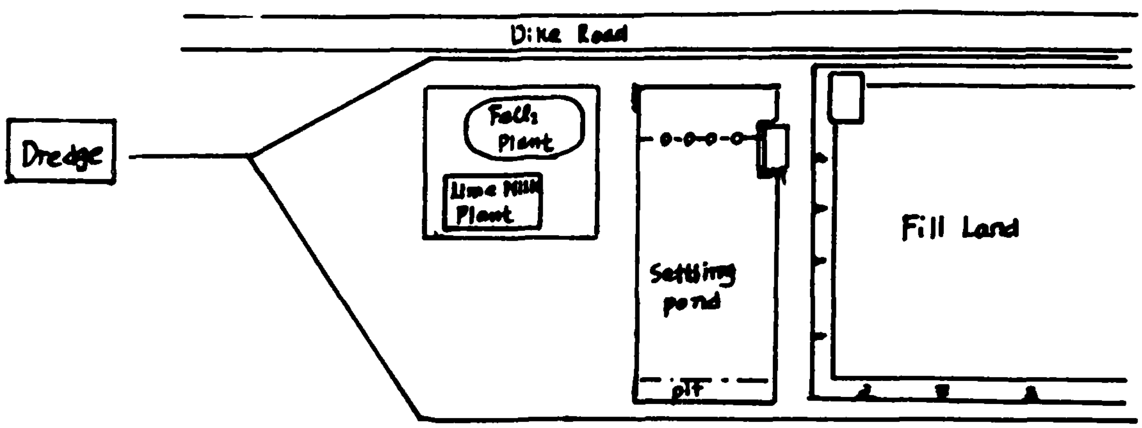


Fig. 18 Site of Deodorization Plant and Settling Pond

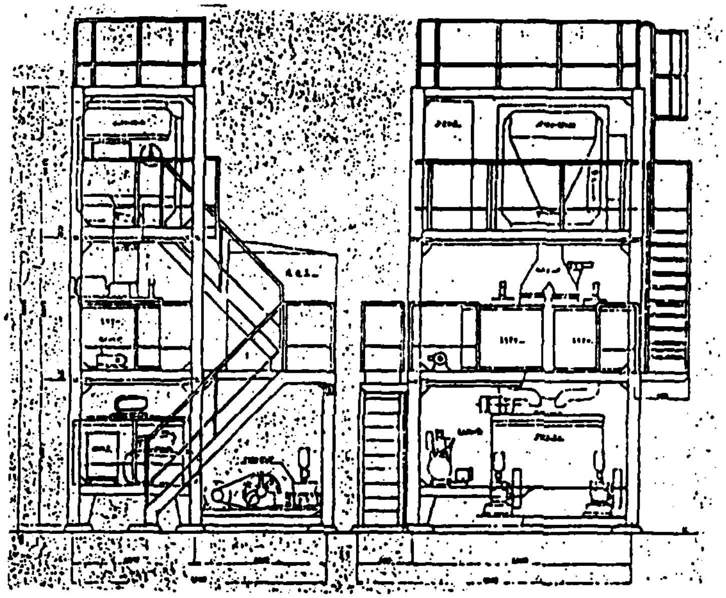


Fig. 19 Slaked Lime Milk Plant

The annexed quantities of deodorants used are indicated in Table 4.

The concentrations of methane and methycaptan after deodorization were nill. Unfortunately, it was difficult to measure the concentration before deodorization because the deodorants were poured directly into pipes. So we could not compare the concentrations before and after deodorization. However, since a strong odor from undeodorized sediment was confirmed in the laboratory, presumably the effects of deodorants would have been great.

5-2. Spill Water Treatment

The criteria for the water quality of the discharge, which was decided by the Mie Prefectural government, are as follows:

pH = 5.8 - 9.0

SS = <50 ppm

COD = <25 ppm

The spill water treatment plant was planned in such a way that the above-mentioned criteria would be satisfied.

The design condition of the plant is set as follows:

Receiving capacity	3100 $m^3/h \times 7$ h/d = 21,700 m^3/d
Quantity of Spill Water	1882 m/h
Retention Time	4 hours
Depth of settled sludge	0.5 m
Effective Depth of Pond	3.5 m

As a result, the size of the pond was determined to be:

Width 30 m × Length 80 m × Depth 4.5 m

Photo 1 shows the settling pond.

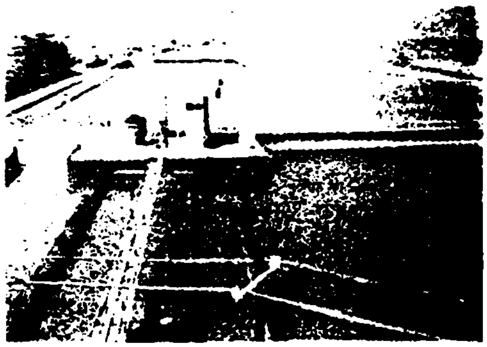


Photo 1 View of Settling Pond and Fill Land

The general view of the pond is shown in Fig. 20.

Retention time was chosen to be 4 hours based on the data of settling tests in the laboratory.

As Fig. 21 shows, the concentration of supernatants decreases rapidly at some settling time. Its value is about 2 - 3 hours for dredged water containing 20% sediment. The spill water quality obtained by the settling pond can be predicted as follows:

	Predicted Values	Criteria
pH	5.8 - 9	5.8 - 9.0
SS	20 - 30	<50
COD	10 - 20	<25

The results of the operation were satisfactory under the criteria shown in Fig. 22. The values of pH during the operation were very

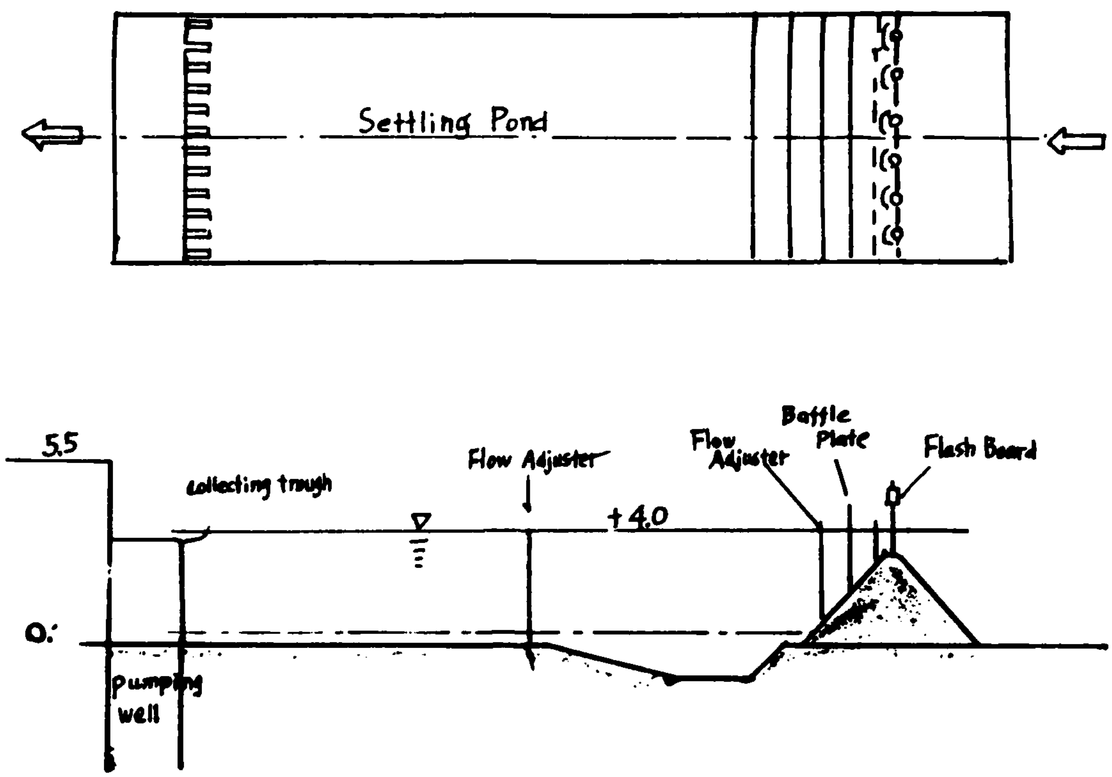


Fig. 20 General View of Settling Pond

normal, showing 7.0 - 8.0 ppm. The concentrations of SS were below 20 ppm in most parts of the operation, and at a maximum below 30 ppm. Therefore, they were much lower than the criteria. The concentrations of COD were below 10 ppm for most of the operation, namely much lower than the criteria value.

The quantities of flocculants, which are needed to exert the above results, are annexed as shown in Table 5.

6. Conclusions

This paper deals with the water pollution problem in the districts near Tsu-Matsuzaka Harbor. In the 1st year of the schedule to remove sediment, 105,000 m^3 was dredged in 1980. The results are not yet conclusive because it is only a part of the whole. Although we cannot comment on the results of dredging at this time, there may be an occasion in the future when we can.

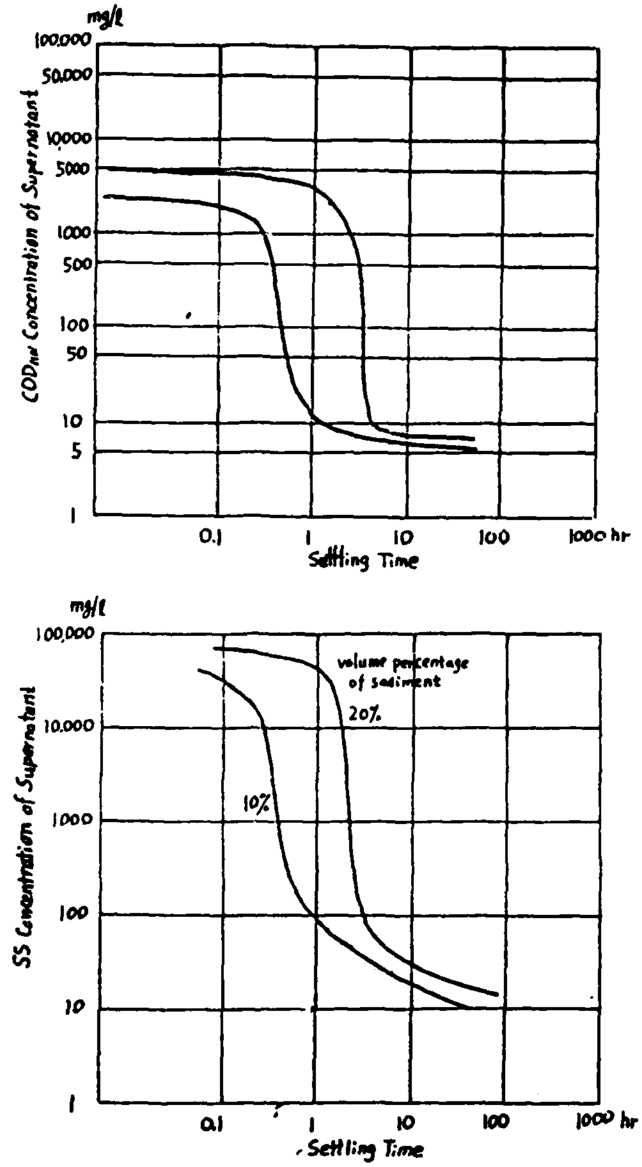


Fig. 21 Relationship between Concentrations of Supernatant and Settling Times

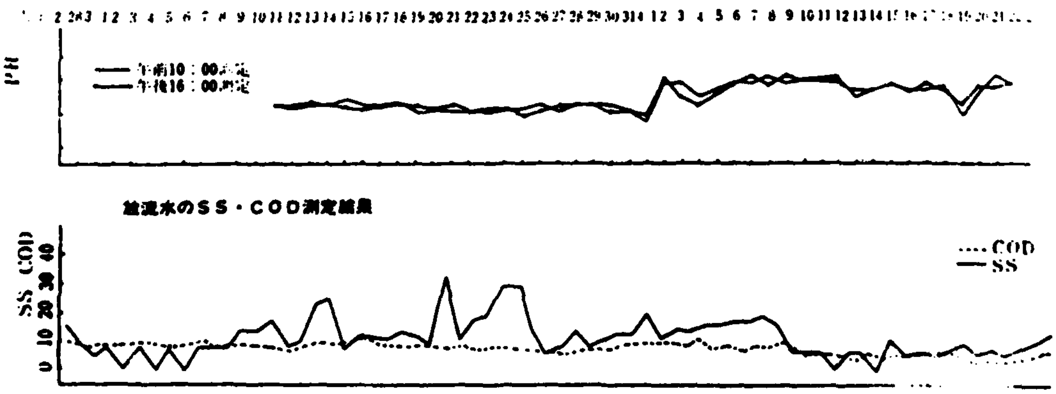


Fig. 22 Concentrations of SS and COD operated

Table 1. Concentrations of BOD of main rivers flowing into Ise Bay

Name of River	Point of Measure	Ranking	1973	1974	1975	1976	1977	1978	Criteria
KISO	YOKOGANO Bridge	B	2.9	1.7	1.9	2.1	1.5	1.3	< 3
MITAKI	MITAKI Bridge	B	—	3.2	3.4	3.8	6.3	7.3	< 3
SUZUKA	OGIIRA Bridge	C	2.0	1.5	0.9	1.3	0.9	1.2	< 5
SHITOMO	EDO Bridge	C	6.1	3.7	4.7	5.0	4.4	6.2	< 5
IZUMO	IZUMO Bridge	A	1.6	1.5	1.2	0.7	0.8	1.0	< 2
KUSHIDA	KUSHIDA Bridge	A	0.8	0.7	0.7	1.1	0.5	0.6	< 2
SEDA	SEDA Bridge	C	9.3	9.1	7.0	5.2	5.5	5.0	< 5

Table 2. Concentrations of COD of seawater

Sēa Area	Points of measure	Ranking	1973	1974	1975	1976	1977	1978	Criteria
YOKKAICHI Harbor	off shore TAIKYO	C	3.6	3.7	4.0	2.5	2.8	3.5	< 8
Tsu-Matsu-ZAKA Harb	off shore TSU	B	4.2	3.9	3.2	4.0	2.7	5.1	< 3
"	off shore KARASU	B	3.0	3.0	2.3	2.9	2.7	6.3	< 3
"	off shore MA-BUZAKA	B	2.8	3.0	3.1	3.2	2.5	4.5	< 3

Table 3. Dredging schedule

	TOTDI Quantities	River SHITOMO	River IWATA	
			Sea	River
1979				
1980	105,000	105,000		
1981	221,000	221,000		
1982	175,000	—	126,000	49,000
1983	50,000			50,000
Total	551,000	326,000	126,000	99,000

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Table 4. Annexed Quantities of Deodorants

Performance / Period	I	II	III	IV
	0–15 d	15–30 d	30–45 d	45–60 d
Dredged Water	21,000 m^3/d 3,000 m^3/h			
Annexed Quantities Solution of 38% as $FeCl_3 \cdot 6H_2O$	average 1,000 ppm max. 5,000 ppm			
Annexed Quantities of Slaked Limes	average 250 ppm max 1,000 ppm			

Table 5. Annexed Quantities of Flocculents

		I	II	III	IV
		0–15 d	15–30 d	30–45 d	45–60 d
During Dredging 7h/d	PAC ppm	50	50	100	100
	Polymer ppm	before pond 5 in pond 1 0.5	5 1	10 1	10 2
after Dredging 5h/d	PAC ppm	50	50	50	50
	Polymer in Pond	0.5	0.5	1	1

THE USE OF HOPPER DREDGES FOR OIL SPILL RECOVERY

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ABSTRACT

Recent tanker collisions and groundings as well as offshore oilwell blowouts have polluted the sea and nearby shorelines with enormous amounts of spilled oil. These catastrophies have clearly indicated that existing technology and available capacity to accomplish clean up cannot deal efficiently with the high volumes of oil on the sea that result from such occurrences.

The Dutch Waterways Board has recently developed an innovation that, when combined with a trailing suction hopper dredge, can provide recovery, control, and storage of up to 10,000 cubic meters of spilled oil. However, due to the safety requirements of a number of maritime regulatory bodies, the vessel must be purpose built. There are very particular rules governing selection of machinery and deck equipment as well as subdivision that preclude conversion of existing hopper dredges.

Having such double purpose ships available will allow immediate response within a specific geographic area to any type of calamity involving oil spills. The size and seaworthiness of these vessels as well as the equipment fitted within allow them to operate efficiently in sea states far beyond the capability of conventional equipment.

INTRODUCTION

The wrecks of the AMOCO CADIZ and the ANDROS PATRIA, the collision between the AEGEAN CAPTAIN and the ATLANTIC EMPRESS, and the blowout of the IXTOE I offshore oilwell in the Gulf of Campache are all examples of calamities that have caused enormous amounts of oil to pollute the sea and surrounding coastal areas. The present methods available to retain, recover, or disperse the resulting oil slick have proven to have disadvantages that preclude them from providing satisfactory results. For instance, chemical control with the aid of detergents, which has been widely employed in the past, and the sand-settlement method both have the disadvantage that the oil remains in the marine environment for a considerable time. In addition, the detergents that were initially used caused toxicity to a certain extent. These drawbacks have been so pronounced that preference is now being given to mechanical methods of control, in which the oil is physically removed.

Other attempts at controlling oil spills include temporarily containing portions of the spilled oil within portable barriers or oil booms and using skimmers to recover and store the oil floating on the water. These skimmers, which may operate on the adhesion, absorption, or other different principals, usually have a very limited storage capacity. In addition, due to the small size of the skimmers and the necessity of ensuring that the oil is contained in a relatively thick layer by artificial means, this method of recovery has succeeded only in calm weather. The ability of skimmers to deal with major oil spills is therefore limited and more effective means are required. The concept of combining an oil spill recovery vessel with a trailing suction hopper dredge was developed by the North Sea Directorate of The Netherlands State Waterways Board as a result of lengthy studies aimed at determining the most effective method of dealing with this problem.

DEVELOPMENT

At a meeting held in Bonn in 1969, the governments of the various European countries that flank the North Sea agreed that, for operational purposes, the sea would be divided into zones. For the Dutch sector, the anti-pollution measures are based on a spillage volume of 30,000 tons of oil. Of this amount, approximately half is assumed to disappear naturally as a result of evaporation and dispersion; the remaining 15,000

tons must be cleared within three days of the occurrence (1). The Board owns a vessel, the SMAL AGT, that was originally used for dispersion of detergents. They fitted this vessel, on an experimental basis, with oil sweeping arms that operate on the "cream-off" principle. Excellent results were obtained when dealing with the spills associated with the AMOCO CADIZ and the ELENI V. However, the capacity of the vessel was not adequate to deal with the large amounts required.

The principal problem was economic: a vessel built purely for pollution control purposes would be idle for a greater part of its life. By its very nature it could not normally be used for other purposes. The Board approached a group of dredging contractors and they agreed to investigate combining the Board's proven principle of oil recovery with that of a modern trailing suction hopper dredge. This vessel should be able to provide a continuous return on the initial investment while possessing a high oil recovery capacity. The group selected IHC Holland, a group of shipyards specializing in the design and construction of dredges, to develop this dual-purpose concept to a working design and build a prototype vessel.

DESIGN CONSIDERATIONS

The vessel had to be designed so that it would be able to operate efficiently in its day-to-day occupation as a trailing suction hopper dredge while maintaining the ability to respond rapidly to any emergency situation. This problem has been discussed thoroughly by van Dooremalen and van Drimmelen (2). The specific considerations include the following:

a. The dredge must be able to be transformed into an operative recovery vessel within a few hours. All necessary equipment must be permanently stored and readily available on board. Any possible adaptations required for the vessel to recover oil should be within the capability of the crew to accomplish while proceeding to the recovery area.

b. Recovery operations must be possible with significant wave heights up to 1.5 meters and a windforce of about 5 on the Beaufort Scale.

c. The capacity of the recovery system was required to be maximized in relation to the size of the vessel and normal weight and power limitations. The arm must be a practical design, be insensitive to fouling material, and be able to work effectively in thin (0.1 mm) slicks.

d. The vessel must be able to maneuver at low speeds in order to deal with small patches of slick dispersed over wide areas.

e. The vessel must be able to discharge the high viscosity oil recovered in its hopper within a relatively short period of time.

f. The vessel must meet all the safety precautions of the regulatory bodies that would normally be applied to tankers.

DIFFERENCES FROM ACCEPTED HOPPER DREDGE ARRANGEMENT

The resulting arrangement differed considerably from a normal dredge. The principal differences are highlighted in Figure 1 and include the following:

a. The dredge pump room is located in its normal position at the forward end of the hopper. However, since it also acts as a cofferdam around the hopper, which is considered to be a cargo tank, it must meet the requirements for that designation. All cabling, lighting, electric motors, etc., must be explosion proof and the ventilation must be upgraded to meet tanker requirements. If the pump room is not separated from the dredge pump engine room by a gas-tight bulkhead, the complete installation must be put out of service during oil recovery operations and the entire space sealed off. (Item 1 in Figure 1.)

b. The wing tanks must be left void to act as cofferdams around the hopper and be fitted with the same electrical and ventilation standards as the pump room. (Item 2 in Figure 1.)

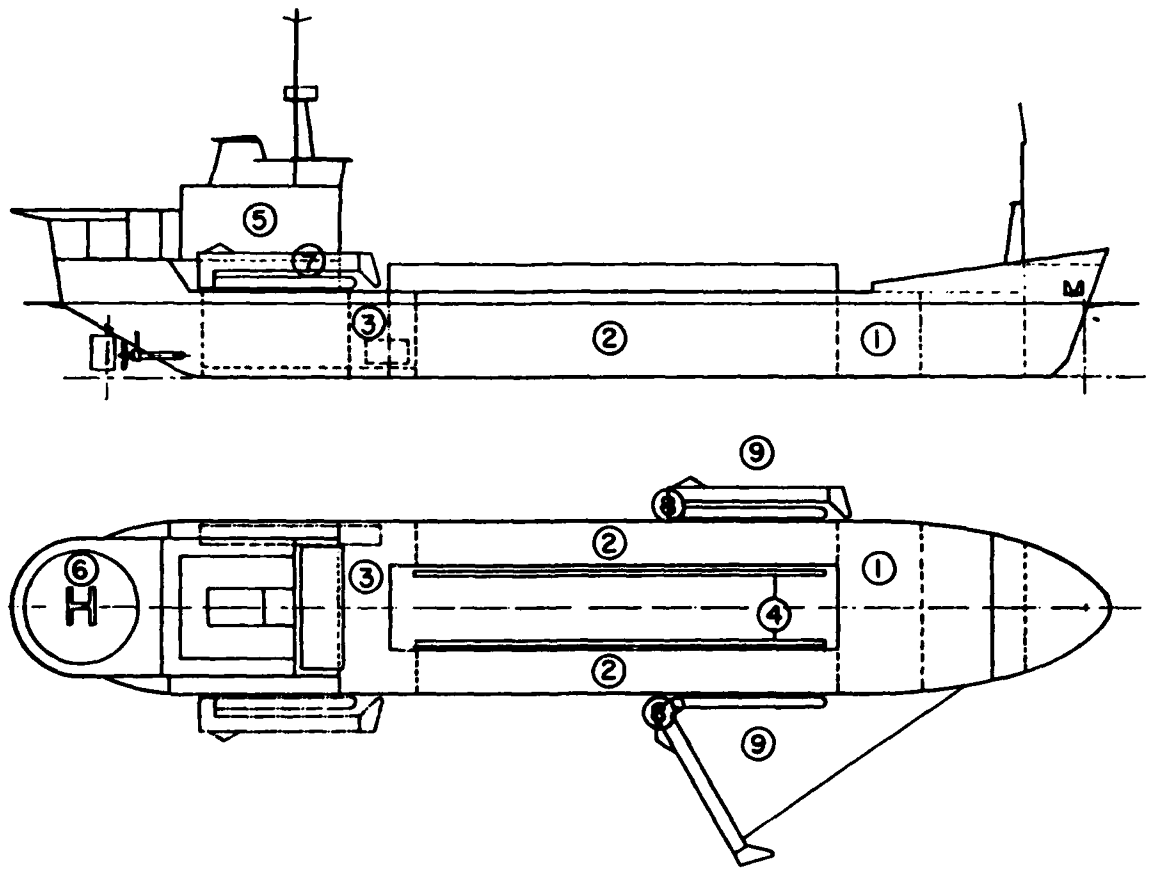

Figure 1. Schematic Arrangement Showing Areas Different From Normal Hopper Dredge Design

c. There is a cargo pump room aft of the hopper that occupies the entire breadth and depth of the vessel. The drive for the pumps in this area must be segregated by a gas-tight bulkhead. The electrical and ventilation standards used for the forward pump room apply. Finally, a permanent means of extinguishing fires must be installed. (Item 3 in Figure 1.)

d. The area above the hopper must be fitted with gas detection devices to continually monitor gas levels. These detectors must be connected to an automatic alarm system that will give a warning when the gas concentrations above the hopper become too high. In addition, these alarms will give notice to the persons responsible for the oil recovery operation that there is a potentially dangerous situation. At that point, a decision will be made on the use of a foam-producing system located over the hopper that has the capability of blanketing the entire hopper surface. Recent full-scale tests have proven that this system is effective in reducing dangerous levels of gas (3). Foam firefighting monitors must be located near the hopper. (Item 4 in Figure 1.)

e. Accomodations must meet fireproof requirements with only limited use of flammable material. The extent will depend on the cognizant regulatory bodies. However, as a minimum, IMCO Resolution 271 should be met. Paneling and insulation must be flame resistant. Each cabin must be equipped with a fire extinguisher and an emergency exit ("kick-out" doors). Supplementary ventilation and gas detectors must be provided. The deck house location must be aft of the hopper and two motor lifeboats with gravity davits must be provided.

f. A helicopter deck is provided to allow expeditious transfer of personnel to and from the vessel before and during an oil recovery operation.

g. The oil recovery arm installation will be discussed separately. (Items 7, 8, and 9 in Figure 1.)

In addition to the above, the requirements state that other areas through the ship must be designed to standards over and above those normally applied to hopper dredges. For instance, the engine room must be located aft and be fitted with self-closing doors at all entrances. All deck machinery must be explosion proof.

These requirements have been set forth by the Dutch regulatory bodies and it is expected that other regulatory bodies would impose the same or, possibly, more stringent requirements. Such precautions are considered necessary since the oil will be carried in an open hopper and may have a flash point lower than 61°C, thus being defined as a flammable liquid. Most of the rules are similar to normally applied tanker requirements, which govern vessels transporting oil in closed tanks. The justification for use of an open hopper to transport oil lies in the recognition that the light fractions of the oil can be expected to evaporate while on the water. It is estimated that crude oil slicks at sea, if remaining more than a minimum of six hours, will have a higher flash point than the 61°C where tanker rules are applicable. During the preliminary tests, the SMAL AGT did not encounter any oil with a flash point below 61°C. However, it is prudent to consider this possibility and all reasonable safety precautions are included in the design.

SWEEPING ARMS

As previously mentioned, the sweeping arms were tested in a smaller ship at sea. The same system is presently being used by the Dutch Waterways Board in cleanup operations in the Rotterdam Harbor area and on inland waterways. It is comprised of port and starboard (Figure 2) arms that are normally stowed next to the deckhouse when not in use (Figure 1, (7)). Each arm contains a hydraulically driven submersible pump (Figure 1, (8)) located at the elbow. The arms may be transported to the forward end of the ship and will extend to an angle of about 60 degrees from the heading (Figure 1, (9)). Both the outer and the inner pontoons are towed by lines attached to deck winches.

The speed of the vessel during sweeping operations is about 2.0 to 3.5 knots. The oil floating on the water is guided to a skimmer in the elbow between the inner pontoon and the arm. The skimmer operates on the "cream off" principle. The film of oil on the water, which is assumed to be relatively thick (in the order of millimeters), is removed from the water by means of a self-adjusting weir. Attaching a float to the weir

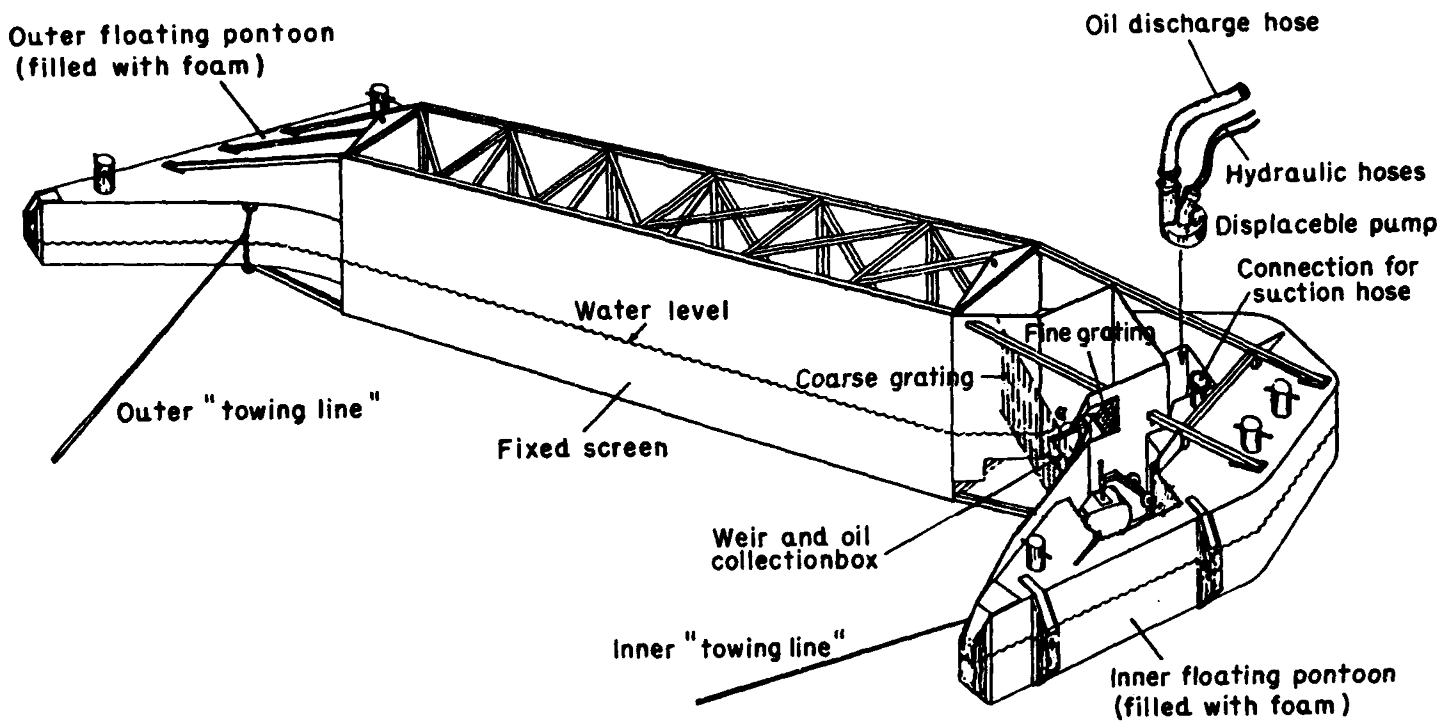

Figure 2. Sweeping arm details

allows it to follow varying water levels due to wave action. The oil is assembled into an inner collection chamber which is fitted with a submerged pump in order to pump the recovered oil into the hopper.

The first full-scale recovery vessel, which has a hopper capacity of about 6000 cubic meters, will be fitted with arms that, considering the beam of the vessel, will provide a sweeping path of about 50 meters width.

The volume of oil that can be cleared per unit time is dependent on the function of the thickness of the layer, the speed of the vessel, and the size of area worked. The capacity of the pump in each arm is 500 cubic meters of water per hour at a pressure of 3.5 bars. This would correspond to about 360 cubic meters of oil with a viscosity of 900 centistokes. Under favorable operating conditions, the oil content of the mixture pumped may be as high as 80 percent.

OPERATING METHOD

As mentioned previously, the vessel will work normally as a hopper dredge performing maintenance work in or near navigation channels normally used by tankers. When an accident occurs, the agency responsible for pollution control will contact the vessel and inform the crew of the nature and location of the occurrence. Upon receiving this call, the vessel stops working as a dredge and heads immediately to the defined area. Any spoil that may be onboard can be discharged during the voyage. At the same time, a team of people experienced in oil recovery will be assembled and transported to the vessel's helicopter deck. A fully equipped communications center is installed onboard for this specific situation.

In order to make the transformation from a dredge to a recovery vessel, the crew must carry out the following operations during transit:

a. Close all gas-tight doors.

b. Switch off all electrical equipment that is not explosion proof.

c. Activate and check all equipment necessary for detection of dangerous gas concentrations.

d. Check the filters in the supplementary ventilation systems required in the engine room and accommodations.

e. Check the foam-producing installation.

At the same time, it is expected that the responsible personnel onboard will have been informed of the properties of the spilled oil and the prevailing sea and weather conditions to be expected in the area.

On arrival at the oil spill, the sweeping arms are put overboard with two hydraulically operated gantries, moved into position, and extended to the 60-degree angle, which can be adjusted by changing the length of the towlines.

Before pumping oil, the hopper is filled with seawater. The oil-water mixture is then brought into the hopper and discharged at a slow speed just below the water surface. This allows turbulance to be kept to a minimum thus allowing separation of the oil and water by virtue of their different specific gravities. A concentrated layer of oil will begin to form at the top of the water in the hopper. An equal quantity of seawater must be pumped out of the hopper through the aft pump room as is being pumped into the hopper through the arm, thus keeping the level in the hopper relatively constant throughout the entire operation. The aft pump room is equipped with separators to extract any oil remaining in the water that is being pumped overboard. Mixing can be expected as the hopper is nearly filled with oil. The oil extracted from the water is pumped back into the hopper while the purified water is pumped overboard.

Upon completion of operations, the arms are brought back onboard and secured in their normal position adjacent to the deckhouse. The oil in the hopper can be transferred at sea to a tanker or, if convenient, off-loaded ashore to an oil processing facility.

CONCLUSIONS

The first full-scale oil slick recovery vessel (Figure 3) built in accordance with the concept described in this paper has just been delivered by IHC to a group of Dutch dredging contractors. Fortunately enough, there has not yet been an occurrence requiring its use in recovery operations and it is presently occupied as a trailing suction hopper dredge maintaining the approaches to Europort. Assuming that the oil sweeping arms prove to be as efficient as the prototypes installed onboard the SMAL AGT, the vessel will provide a cleanup capability that is larger than all other such equipment in the area combined. At the present time, the possibility of conducting tests using a nonpolluting medium such as mineral oil is being investigated. The results of these tests or, if necessary, performance during an actual oil spill cleanup operation, will be reported in the technical literature as they become available.

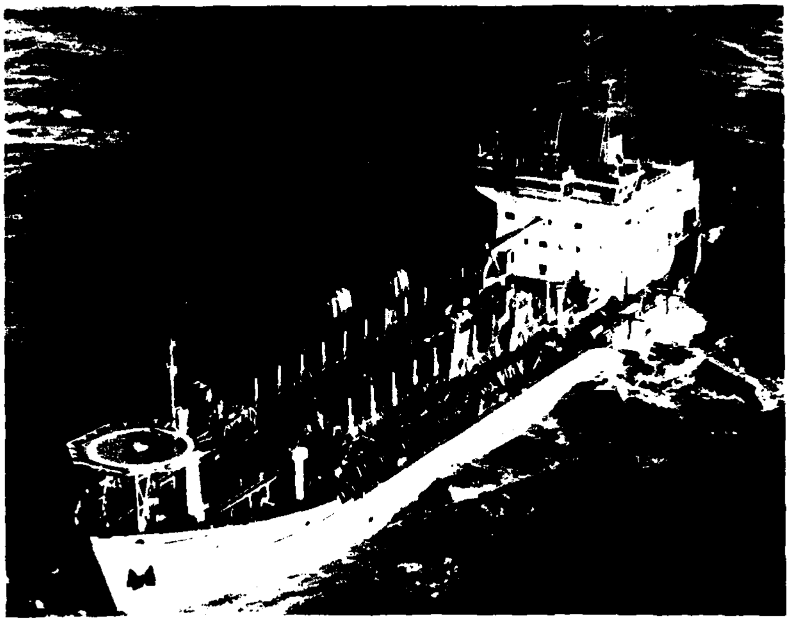

Figure 3. First Full Size Combination Hopper Dredge and Oil Recovery Vessel

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THE CENTER FOR DREDGING STUDIES AT TEXAS A&M UNIVERSITY

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ABSTRACT

This paper describes the formation, history, and activities of the Center For Dredging Studies at Texas A&M University. The Center was established in June 1968 as a result of conferences between educators, representatives of the dredging industry and manufacturers, and officials of the University. The Center is part of the Department of Civil Engineering and Texas Engineering Experiment Station and is supported by gifts and research grants from the dredging industry and government. Extensive research facilities available to the Center are housed in the Hydromechanics Laboratories. In addition to research and industrial testing, the Center's activities include the teaching of university courses as well as annual seminars and short courses. Dissemination of information is through Newsletters and Abstracting Service. Dredging-related research conducted at the Center and at the University is briefly described and a listing of reports and publications is included.

INTRODUCTION

In June 1968, the Center For Dredging Studies was established at Texas A&M University. It was felt at that time there was a definite need for the establishment of such a Center in the United States, particularly in view of renewed interest in greater utilization of marine resources and increased activities in estuaries along the shore and offshore. Both State and Federal governments were making a concerted effort to develop new interests and facilities to stimulate research and development of marine resources. [1]

The Center is housed in the new 6440-square-foot addition to the Hydromechanics Laboratories as part of the Civil Engineering Complex on the campus of Texas A&M University, College Station, Texas.

The initial objectives of the Center were:

(1) To establish a first-class dredging laboratory incorporating:
   (a) a large dredge pump test loop
   (b) a cutter head towing tank
   (c) a four-dredge pump dredging system loop
   (d) a pipeline loop system
   (e) a small dredge pump wear and erosion test stand
(2) To conduct basic and applied research to improve:
   (a) dredge pump efficiency
   (b) dredge pump cavitation characteristics
   (c) cutter head efficiency, etc.
(3) To study the use of jet pumps in suction lines of dredge pumps thus increasing dredging depth.
(4) To develop design criteria for:
   (a) dredge pumps
   (b) jet-assist pumps
   (c) drag heads
   (d) gas removal systems
   (e) multiple-dredge pump systems
   (f) booster pumps, etc.
(5) To determine more accurate information on pipe friction losses for various materials pumped and head losses in elbows, wyes, ball joints, etc.
(6) To provide an industrial testing facility to solve specific problems for the sponsors.
(7) To publish a quarterly Newsletter and provide an Abstracting Service covering all publications of interest to the dredging industry. The abstracts are issued monthly.
(8) To assist the dredging industry in staying abreast of the latest developments. Yearly dredging seminars are arranged.
(9) To offer short courses periodically to satisfy the needs of industry and government for continual review through refresher courses on dredging fundamentals, including special applications and envirormental effects.

Many of the original objectives have been achieved by the Center, particularly those dealing with the establishment of physical facilities, research on dredge pump characteristics, and pump cavitation characteristics.

Since the National Environmental Policy Act of 1969, the Federal Water Pollution Act of 1972, the Coastal Zone Management Act of 1972, and subsequent amendments and Federal and State rules and regulations, the activities of the Center gravitated toward studies of environmental impacts of dredging and assisting in the preparation of Environmental Impact Statements as required by law.

RESEARCH CONDUCTED AT TEXAS A&M UNIVERSITY

Research conducted may be classified under the following headings:

(1) Dredge pump characteristics
  (a) Dimensionless presentation of pump characteristics
  (b) Dimensionless presentation of cavitation characteristics
(2) Flow around a suction inlet
(3) Analysis of the dredging system
  (a) Systems engineering
  (b) Analytical model of a cutterhead dredge
  (c) Operating characteristics of cutterhead dredges
(4) Dredging methods
  (a) Dredging in India
  (b) Dredging of dead coral
(5) Disposal of dredged material
  (a) Determination of bulking factors
  (b) Unconfined disposal
  (c) Confined disposal
  (d) Erosion of islands
  (e) Dewatering of confined dredged material
(6) Maintenance of intra-coastal dredged channels
(7) Design of ship channels (mathematical model)
(8) Offshore mining
  (a) Shallow water--sand, gravel, and shell
  (b) Deep water--manganese nodules
  (c) Development of offshore cutterhead dredges
(9) Environmental effects of dredging

Dredge Pump Characteristics

a. A new method presenting pump characteristics in a dimensionless form has been developed. This method simplifies presentation of characteristic curves; checking the experimental results; comparing

the characteristics of pumps designed by different manufacturers; etc. [2,3].

b. Research on the effect of solid-water mixtures on pump cavitation led to the following conclusions:
   . Since cavitation inception and intensity depends on vaporization of liquid in the solid-water mixtures, suction head and net positive suction head must be expressed in feet of mixture (ft-lb/lb). Heads expressed in feet of mixture do not depend on the density of the mixture [3].
   . The Reynolds number based on the apparent viscosity of silt-clay-water mixtures has very little effect, if any, on the cavitation index.
   . Dimensionless presentation of cavitation characteristics is the most efficient way of presenting the information.

Flow Around a Suction Inlet [4]

. A mathematical model based on potential flow has been developed for a suction inlet treated as a point sink. However, because of viscous and boundary effects such a model is not accurate.
. Viscous and boundary effects create separation zones and large-scale circulation patterns which alter the streamline patterns.

Analysis of the Dredging System

a. Operating a cutterhead dredge is very complicated since a great number of variables affect its performance. A mathematical model of a cutterhead dredging system was developed by Basco [5,6,7]. The model examines the four major limitations of solids output, i.e. horsepower, cavitation, line plugging, and dislodgement limits. The model provides the dredging contractor with a tool to examine the operating efficiency of any given system. An obvious need exists to provide feedback from day-to-day operations in order to improve dredging efficiency.
b. Substantial differences in the production of several commercially available pumps were demonstrated for both power and cavitation limitations on solids output. A model dredge program may be used to study the relative effects of many variables on the solids output rate of the system [8].
c. A survey was conducted to evaluate the operating characteristics of cutterhead dredges in the USA and overseas. The results indicate that relatively few dredges are able to operate under wave conditions over five feet and that few of the U.S. and Canadian dredges have adequate instrumentation, but a majority of foreign dredges have magnetic flow meters, density meters, and/or total production meters [12].

Dredging Methods

a. An examination of dredging problems encountered at several major Indian ports was conducted and possible solutions were suggested. Special attention was given to dredging problems occurring during the monsoon season, since seventy percent of the siltation occurs during that season. Improvements in dredging equipment were suggested in the context of existing problems [10].

b. A study was conducted on the dredging of coral and its use as construction material. The engineering characteristics of coral were examined and it was found that coral has been used successfully as a construction material. Dead lagoon corals and sediments can be dredged hydraulically [11].

Disposal of Dredged Material

a. A laboratory method has been developed to determine the bulking factors of materials; the equipment includes a special impeller to simulate the dredging process in preparation of soil slurries. Some twenty-seven soil samples representing a variety of consolidated sandy and silty clays, typical to the Texas coastal areas, were examined. Equations derived from data relate bulking factors to salinity, average void ratios, percent silt and clay, and in situ water content. Use of these equations to predict the laboratory-determined bulking factors results in an accuracy ranging from ± 18 to ± 30 percent [13].

b. A field study of an unconfined dredged material disposal area revealed that, immediately after deposition, over 40 percent of the dredged material (based on original in situ volume) left the designated disposal area and spread out over the bay floor as a mud-density flow. Eventually, dredged material covered an area about three times larger than that of the original designated disposal area [14].

c. Methodology for management of confined disposal areas has been developed to increase efficiency through dewatering methods [15]. A laboratory study evaluated the dispersion jet flow in a confined 3-dimensional tank simulating a confined disposal area. It was determined that baffling as well as increased water depth improves performance [16].

d. The physical processes causing the erosion of dredged material mounds cause infilling of dredged channels. A field study at selected disposal sites on the Texas coast has been carried out to determine the important environmental factors causing the erosion of these islands. Hydraulic model studies of selected cohensionless dredge-material islands have been conducted to predict the long-term fate of these islands under wave and current action. The influence of additional factors such as higher water depths, steeper waves,

inland spacing and orientation, and small magnitude currents was also considered. Recommendations have been made to improve disposal practices of dredged material which will result in reduced silting of navigation channels.

e. A field study by Brown and Thompson [18] was undertaken to evaluate the influence of evaporation and drainage on the rate of densification of confined dredge materials at several locations. Several methods to increase the surface drainage have been proposed.

Maintenance of Intra-Coastal Dredged Channels

A study was conducted by James et al. [19] to identify potentially adverse environmental factors other than dredging associated with the operations and maintenance of the Texas Gulf Intracoastal Waterway (GIWW). The Waterway can transport water, pollutants, aquatic plants, and animals from one river system to another. Fresh water inflows carrying a concentration of nutrients and metals appeared to be the major source of pollution in GIWW. The GIWW and associated dredged material islands have the potential of modifying circulation patterns and salinity levels in the bays and estuaries.

Another study by Herbich [20] evaluated bank erosion along the GIWW, siltation of the waterway, frequency of dredging, and proposed disposal methods of dredged material.

Design of Ship Channels

A mathematical model for the design, operation, and economic analysis of deep-draft navigational channels was developed by Gates and Herbich [21]. The channel design module model determines the vessel's reaction to the effects of squat, changes of salinity, boundary layers due to vessel motion, current and wind changes in the neutral steering line due to asymmetry in the channel cross-section, bank suction, and other phenomena.

Another study [22] examined the need for deeper U.S. ports and evaluated the ship channel criteria in terms of minimum width and depth requirements for various sized vessels.

Offshore Mining

a. Shallow water mining along the U.S. coast has not developed because of lack of information on the location and magnitude of deposits offshore. Development of new tools for exploration of sand, gravel, and shell deposits is recommended [23]. Also, shallow water mining of sand, gravel, and shell may be considerably enhanced by developing seaworthy pipeline cutterhead dredges [24].

b. Deep water manganese nodules were the subject of several studies by Flipse and Herbich [25,26]. Recent testing of deep-ocean mining systems demonstrated the technical feasibility of deploying needed equipment at sea for dredging manganese nodules from the deep ocean floor. There is a need for in-depth analysis for the purpose of systems optimization.
c. There is a need for the development of a sea-worthy pipeline dredge capable of operating in 2-meter-high waves and surviving 4-meter waves. The stability of a cutterhead dredge may be increased by employing a semi-submersible or Catamaran twin-hull design [24].

Environmental Effects of Dredging

The stress placed on the environment by modern technological processes signifies a clear need for studying the role played by the dredging industry on the environment. The environmental impact from disposal of clean dredged material appears to be minimal but special arrangements must be made for the disposal of polluted material [27].

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APPENDIX I

FACILITIES

As part of the Center, a large dredge pump test loop and a slurry pipeline test loop are available for research. The primary components are an 800-cubic-feet vacuum tank, a 300-horsepower electric motor, and a 300-horsepower variable-speed drive. The pipeline test loop consists of three 180-foot-long pipes with diameters of four inches, six inches, and eight inches. Pressure taps and monometer monitor losses along the entire length of each pipe; power is supplied from the dredge pump test facility. In addition, a magnetic flow meter, a nuclear density meter, and a production meter have been installed in the test loop system.

Other facilities in the Hydromechanics Laboratories include: a long two-dimensional wave channel, a large three-dimensional wave channel, towing tank, two variable-slope open channel flumes, and an automatic data-acquisition system.

STUDIES ON LAKE POLLUTION OF NAKANOUMI AND ON ITS RESTORATION

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Izumo Work Office
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Ministry of Construction

Abstract

Lake Nakanoumi is a typical brackish lake in our country. In this lake as well as in other lakes eutrophication has advanced in recent times. To meet this environmental problem, the Izumo Construction Office of the Ministry of Construction performed pollution studies recently and is now studying its restoration. We report here an outline of those studies.

1. Background of Lake Nakanoumi

Lake Nakanoumi is situated at latitude 35°30'N and longitude 140°E. It faces the Nippon Sea and lies in the western part of mainland Japan. Its area is 9600 ha and is the fourth largest lake in our country. Its basin area is 2070 km^2 and has a population of about 450,000 people. The district around the lake, namely, Izumo country, is sometimes called a mythological land or native place, because its land and climate were described in a topographical book, Izumo Land Descriptions, which was written in 712, and until recently its land and climate have been preserved in a satisfactory state. The lake is located in the downstream section of the River Hii, which flows in this region.

The lake surface level is nearby equal to that of the Japan Sea. Therefore, seawater flows into the lake. About half the volume is fresh water and the other is seawater. The mean depth is only 5.4 m.

Lake Nakanoumi is connected at its upper part to Lake Shinjiko, wich has a lake area of 8000 ha and a mean depth of 4.5 m. As Fig. 1 shows, 3 big cities, Izumo, Matsue, and Yonago, lie around these lakes.

The reclamation works are now under construction on a large scale. This project has the aim of reclaiming about 1/3 of the lake area and to change brackish lake water to fresh water and to utilize it as service water. Therefore, the limnological environment of Lake Nakanoumi will undergo an upheaval in the near future.

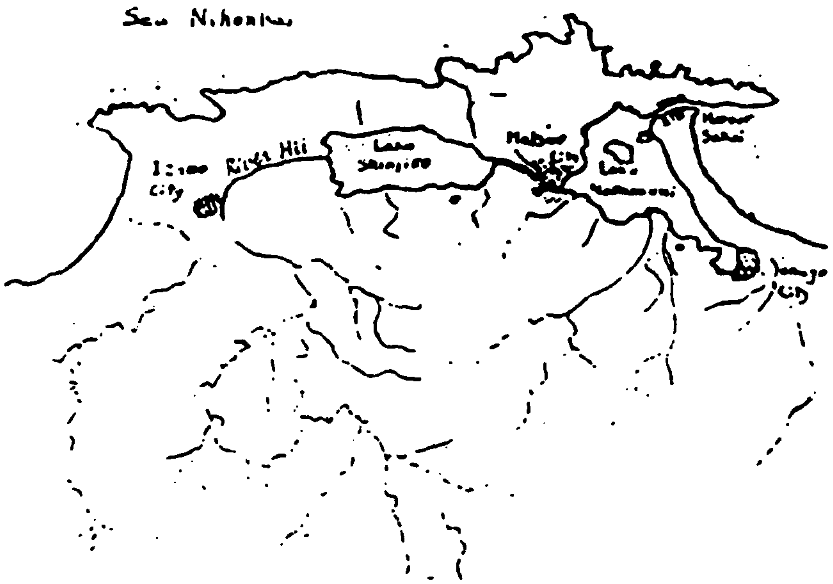


Fig. 1 Basin Area of Lake Nakanoumi

2. Water Quality

The water quality of the lake has the following features:

1) There is a stable salinity stratification.

The concentration of chlorine is 9000 - 12,000 ppm at the upper layers and 15,000 - 17,000 ppm at the deeper ones (Fig. 2). The salinecline exists at a depth of 3 - 4 m.

2) Mixing of water rarely occurs.

Since the difference in water density due to salinity is much larger than the difference due to water temperature, mixing of water rarely occurs even in spring and autumn.

3) The concentration of DO at the bottom becomes very low in summer (Fig. 3).

Due to the deoxygenating action of sediment, the dissolved oxygen in water above the sediment is consumed and the water becomes oxygen deficient.

4) The concentration of T - P at deeper layers becomes larger in summer.

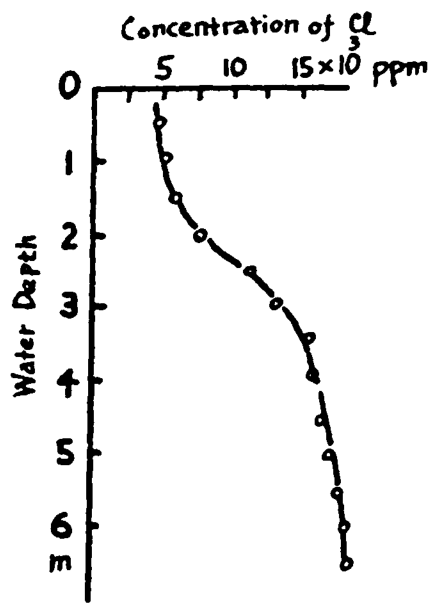


Fig. 2 Salinity Stratification

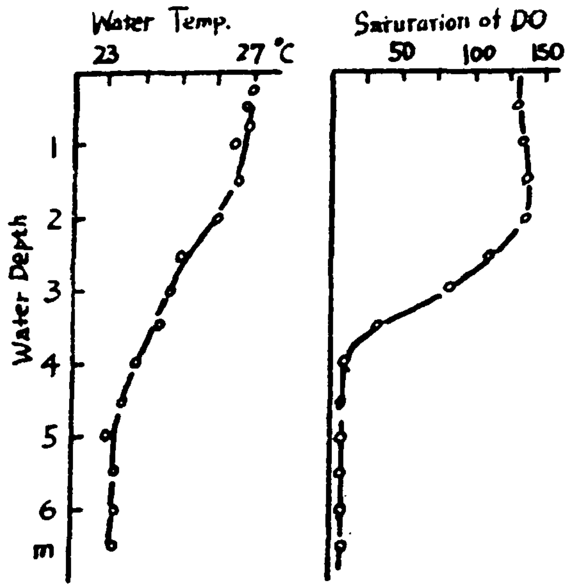


Fig. 3 Vertical Distribution of Water Temp. and DO

The anaerobic condition of bottom lake water promotes the release of phosphorus remarkably and then creates a highly eutrophicated state. The concentration of PO_4 - P is much larger in deeper layers than in the upper layers.

As Figure 4 shows, most of the released quantities of phosphorus are PO_4 - P.

5) Algal growth potentials (AGP) are high.

The results of AGP tests, which were performed using Cyclotella as a cultured plankton, are shown in Fig. 5. The values of AGP of Lake Nakanoumi are higher than those of Lake Kasumigaura. It is noticed that the addition of nitrogen makes the AGP values higher.

6) There is a seasonal variation of T - P concentration in water.

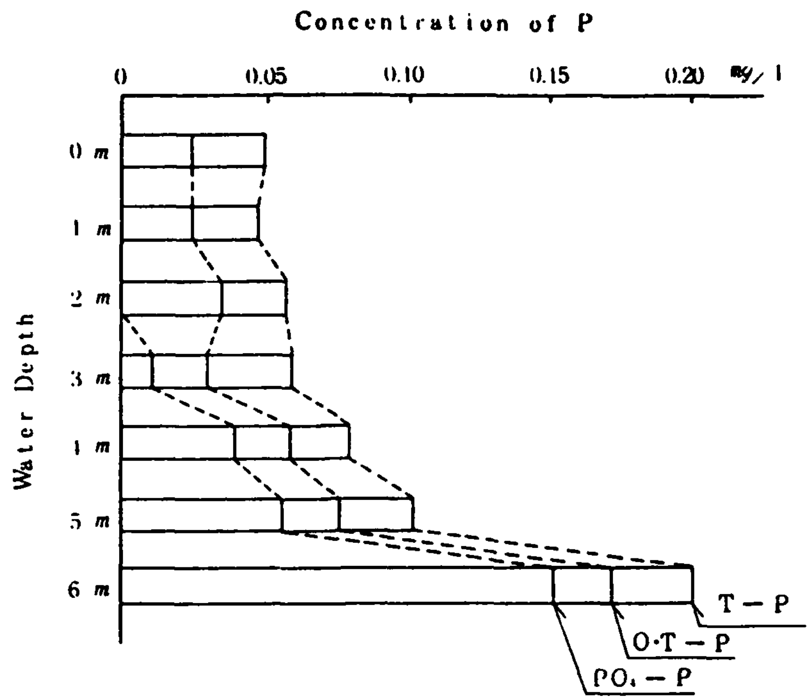
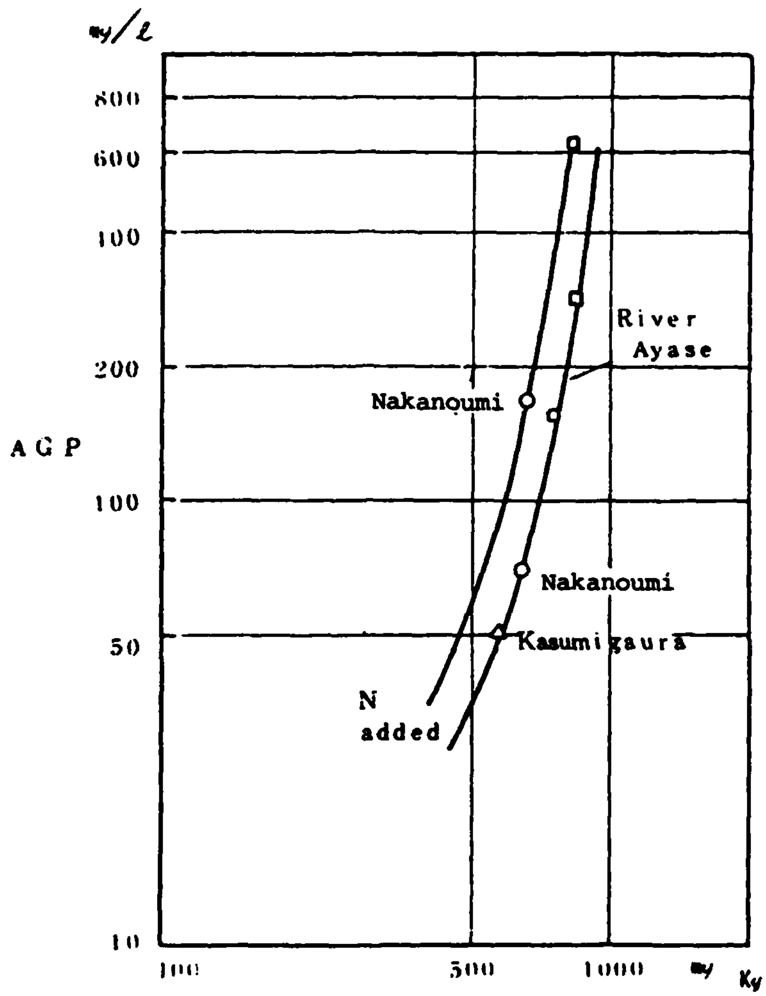


Fig. 4 Vertical Distribution of T - P and PO_4 - P

The concentrations of T - P are between 30 - 50 μg/l in the period from January to June (Fig. 6). But they begin to increase rapidly from July and reach their maximum value of about 90 μg/l in summer. It seems that the peak is not sharp and lasts for about 4 - 5 months. It is presumed that the peak is created by the released materials (phosphorus) from the sediment.

7) There is also a seasonal variation of T - N concentrations in water. The seasonal variation of T - N concentrations in water behaves a little differently from that of T - P. The peak is reached in April (Fig. 7). It may be created by inflowing pollutants, not by released materials. In summer the second peak is generated, but it is smaller. This may be



Concentration of P in Sediment

Fig. 5 AGP Test Results

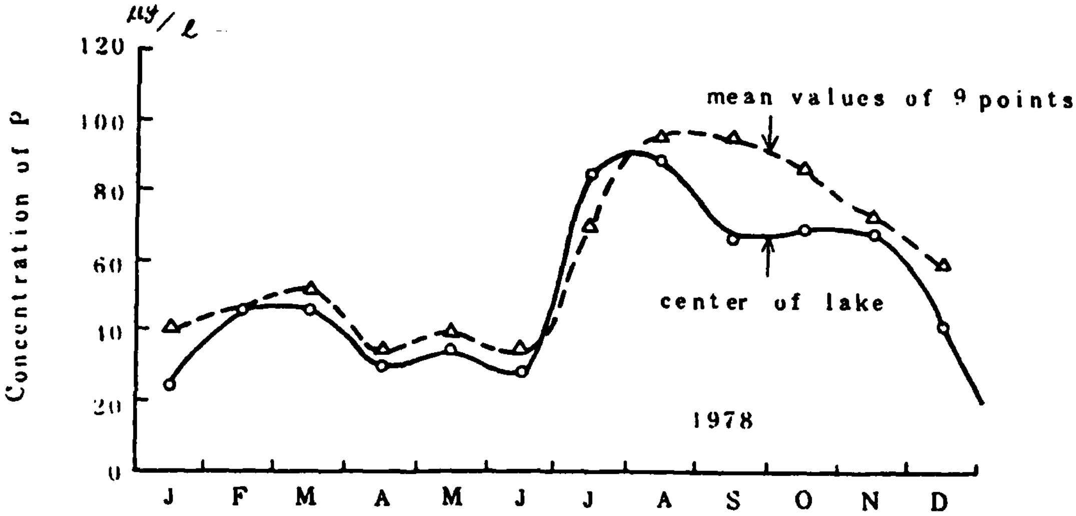


Fig. 6 Seasonal Variation of T - P in Water

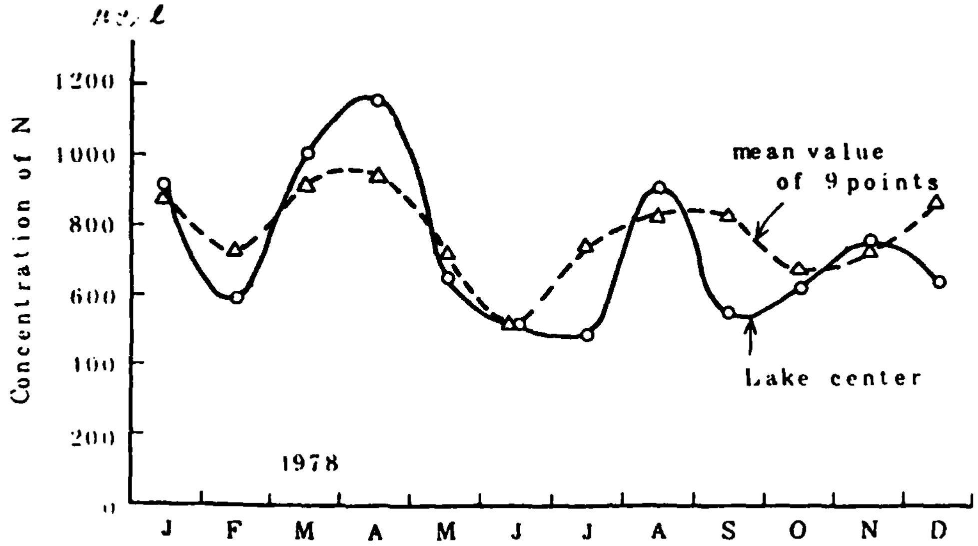


Fig. 7 Seasonal Variation of T - N

due to the release of nitrogen from the sediment.

8) Crops of red tides exist.

The red tides are generated off the southern shore and at Yonago Bay in spring (March - May) and in autumn (Nov. - Dec.). The dominating species is Prorocentrum. The concentrations of chlolophyll - a, - b, and - c are plotted in Fig. 8. Plankton are distributed only in the upper 1.5 m of depth.

3. Sediment Properties

The sediment has a black, black-gray, gray, and light-gray color in turn according to sediment depth. The distinction of sediment colors denotes the degree of pollution (Fig. 9).

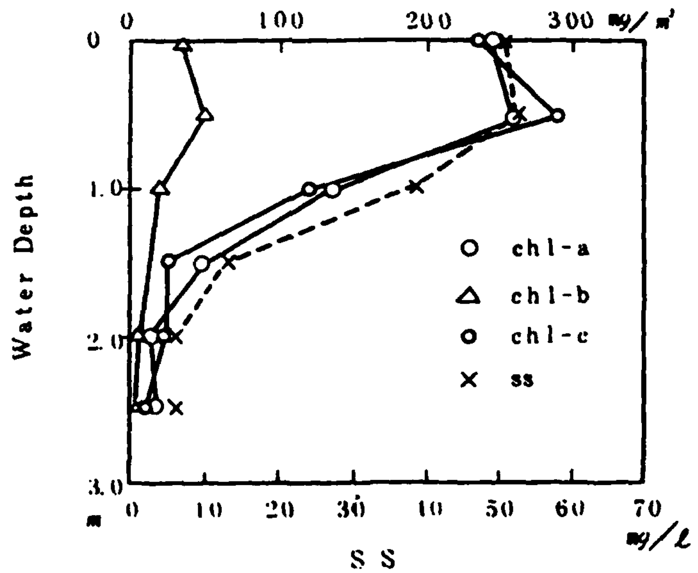


Fig. 8 Vertical Distribution of
Chl - a, - b, and - c

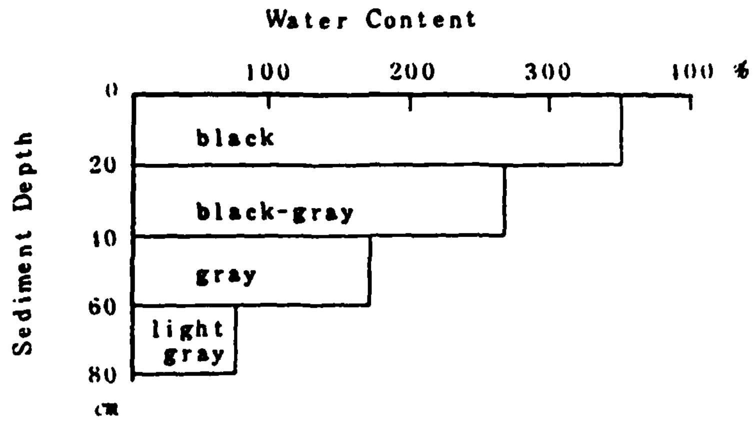


Fig. 9 Relationship between Water Content and Sediment Color

3-1 Water Content

The black surface layer has a thickness of about 20 cm and a water content of 350 percent. If we regard the polluted sediment as the black and black-gray portion, the thickness of pollution may be 40 cm.

3-2 Ignition Loss

The black layer has a mean value of 16 percent Ignition Loss (Fig. 10). The unpolluted layer, namely the light-gray one, has a value of only 4.5 I.L. From the view of I.L., the black and black-gray portions represent the polluted state of the sediment.

3-3 Concentration of COD

The concentrations of COD in the black and black-gray layers are 36.6 mg/g, and 30.0 mg/g, respectively (Fig. 11). Between the black-gray and gray portion there is a distinct difference in COD

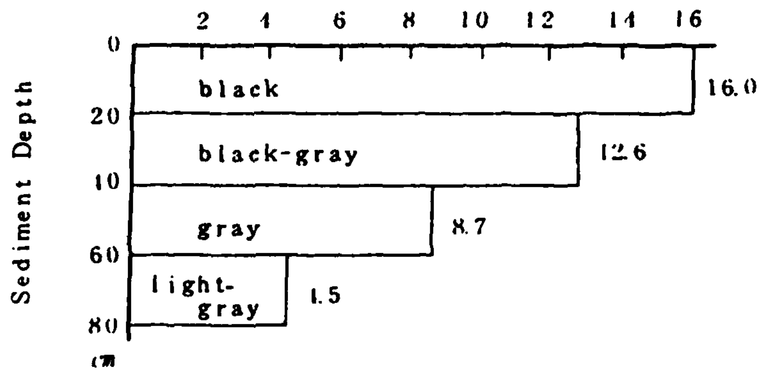


Fig. 10 Relationship between I.L. and Sediment Color

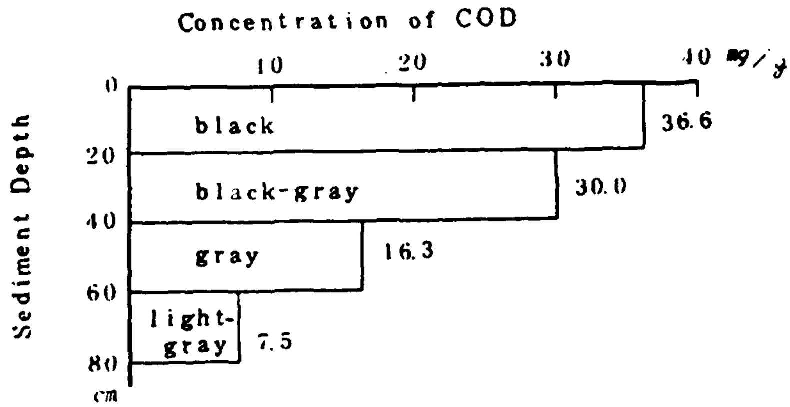


Fig. 11 Relationship between COD and Sediment Color

concentrations. Therefore, a boundary between polluted and unpolluted sediment exists.

3-4 Concentration of T - P

The concentration of T - P in the sediment is distributed in a vertical profile as shown in Fig. 12. The concentration at the sediment surface is largest and decreases with sediment depth. Apparently it approaches some background value at a certain depth. This point of convergence represents a background value proper to an unpolluted state.

3-5 Concentration of T - N

The concentrations of T - N at the surface and in the light-gray layers are at maximum about 5 mg/g and 1.5 mg/g, respectively (Fig. 13). The ratio of N/P in the sediment is 5/1.5 = 3.3. In comparison, the ratio of N/P in water is $\frac{774}{60.7} = 12.75$.

3-6 Release Rates of Nutrients

The release rates of phosphorus are shown in Fig. 14.

The release rates of the black-gray layers are much larger than those of the gray layers. Notice that the released rates of phosphorus are in proportion to the content of phosphorus contained in sediment. The same tendency is recognized for T - N (Fig. 15).

Generally speaking, the release rates of sediment in Lake Nakanoumi are comparatively high.

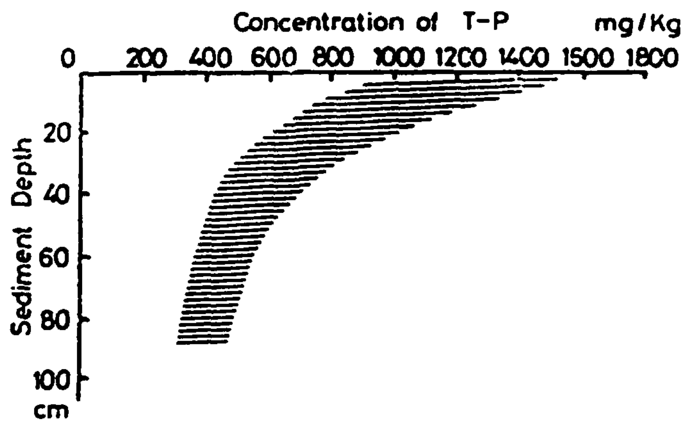


Fig. 12 Distribution of Phosphorus Concentration

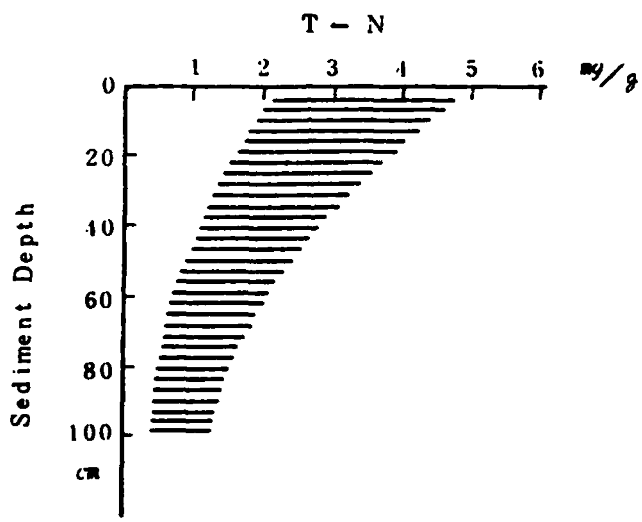


Fig. 13 Distribution of Nitrogen Concentration

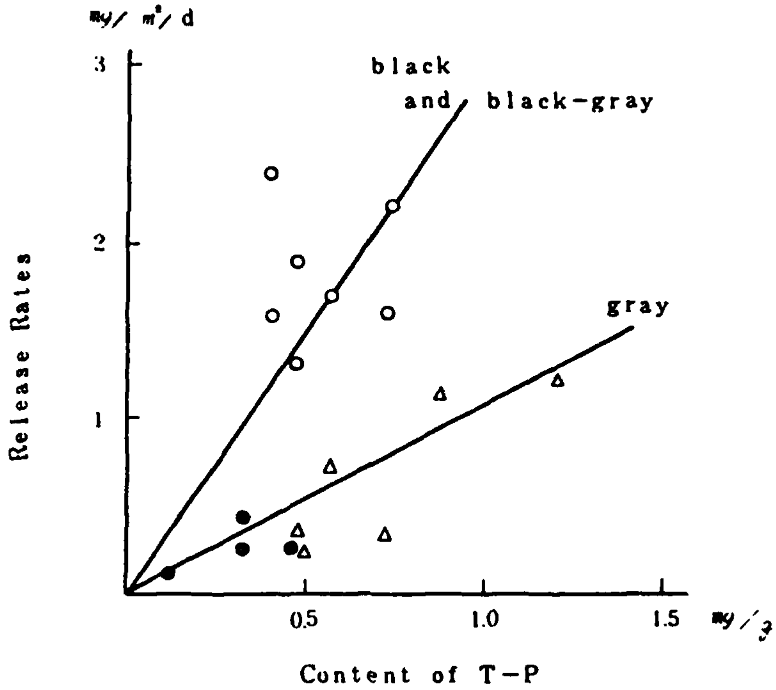


Fig. 14 Release Rates of Phosphorus

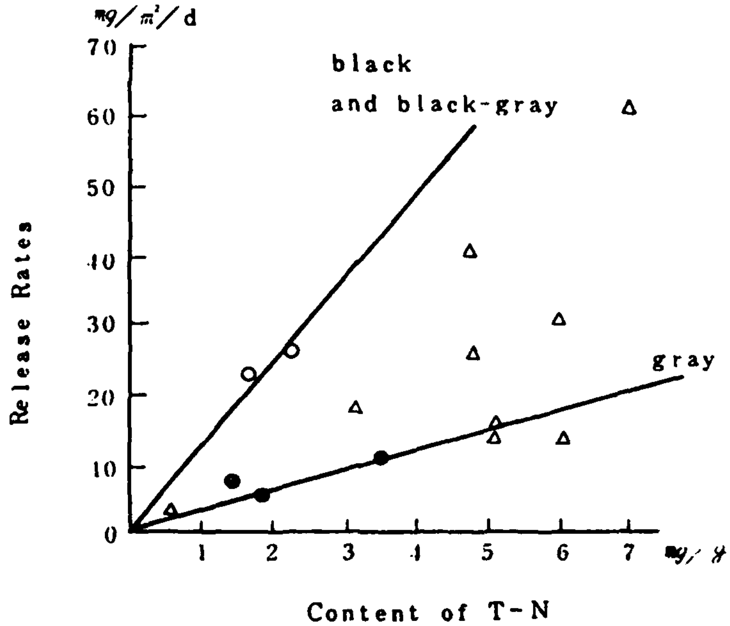


Fig. 15 Release Rates of Nitrogen

4. Distribution of Sediment

As shown in Fig. 16, sediment is spread widely over the lake in a thin layer below 10 cm. The places of thick accumulation are as follows.

Estuary of River Ohashi	10 - 90 cm
Estuary of River Iinashi	10 - 90 cm
Inner part of Yonago Bay	10 - 90 cm

The total amount is estimated to be 1,500,000 - 2,000,000 m^3.

5. Accumulation Rate of Sediment

The accumulation rate and the accumulated ages (Fig. 17) of sediment were measured, using radio-isotope Pb210.

Sediment depth, cm	Accumulated ages
0 - 15	1979 - 1927
15	1927
20	1907
25	1883
30	1851
40	1777
50	1714
60	1654
70	1585
80	1491

The sediments of 20 cm, 40 cm, and 80 cm in thickness were accumulated 74 years, 204 years, and 490 years ago, respectively.

From these chronological measurements the accumulating rates were estimated at 2 mm/year for a 15 - 30 cm sediment depth, 1.5 mm/year for

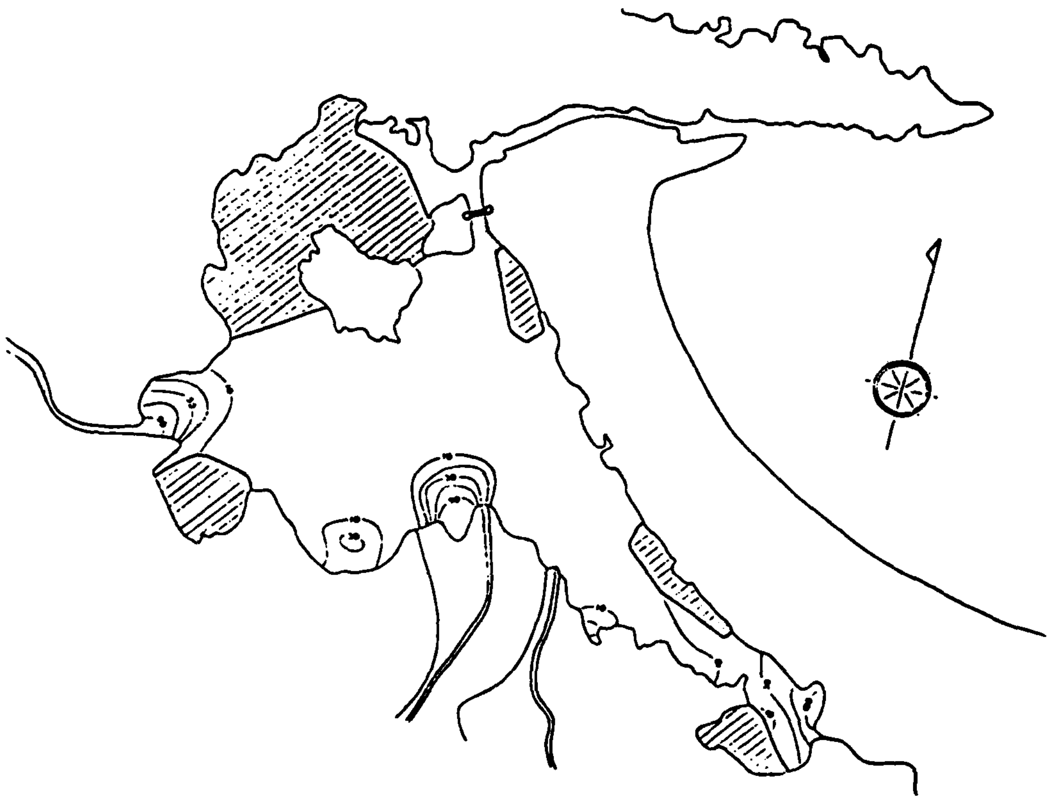


Fig. 16 Distribution of Sediment

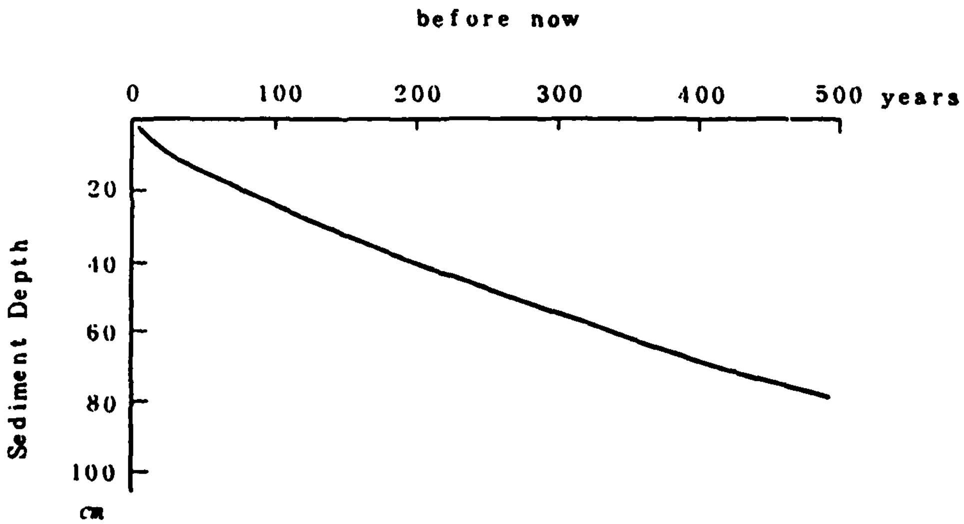


Fig. 17 Ages of Accumulation

a 30 - 50 cm sediment depth, and 1.3 mm/year for a 50 - 80 cm sediment depth.

6. Restoration Project

As mentioned before, it is clear that Lake Nakanoumi is highly eutrophicated. In order to restore it, it is necessary to take 2 countermeasures: (1) restrict the influx of pollutants and (2) reduce pollutants in the lake by removing sediments. As regards the former, the construction of a sewage plant in Yonago City (population 130,000 people) is projected to be finished by 1987. The quantities of nitrogen and phosphorus, which flow now into the lake, are shown in Fig. 18 and Fig. 19. Looking at these pollution origins and causes, we must endeavor to reduce these influx quantities. With regard to the removal of sediments, it is planned that 500,000 m^3 of sediment, which corresponds to half the total amount of sediment accumulated in Yonago Bay, will be removed by the time the sewage plant is completed. The cost is 4 billion yen, and as a result 17 ha of reclaimed land will be made inside the lake. In projecting sediment removal it is important to determine the thickness of the sediment to be removed. The criteria of removal were decided from various points of view as Table 1 shows. From the table it is clear that the black and black-gray colored sediment should be removed. The before-mentioned amount of 500,000 m^3 of sediment was obtained from these considerations.

Regarding the restoration project, there are some problems to be considered. One is concerned with the effects of newly settled materials

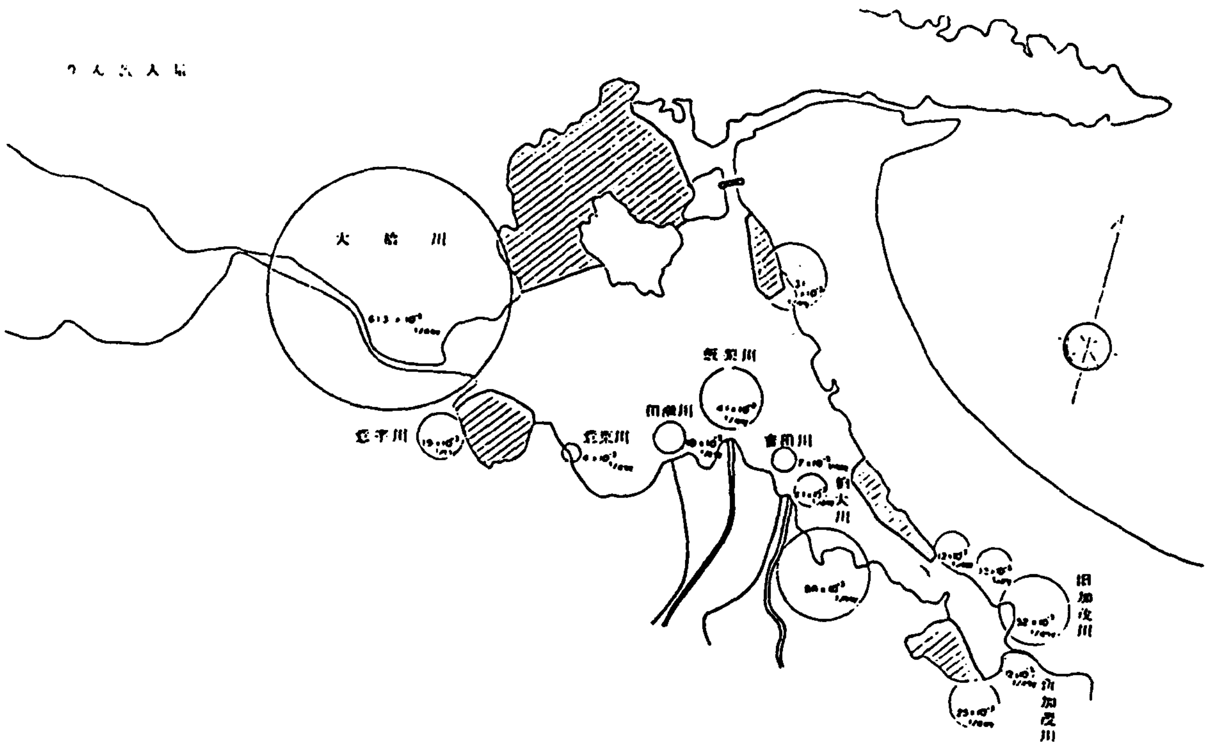


Fig. 18 Influx of T - P

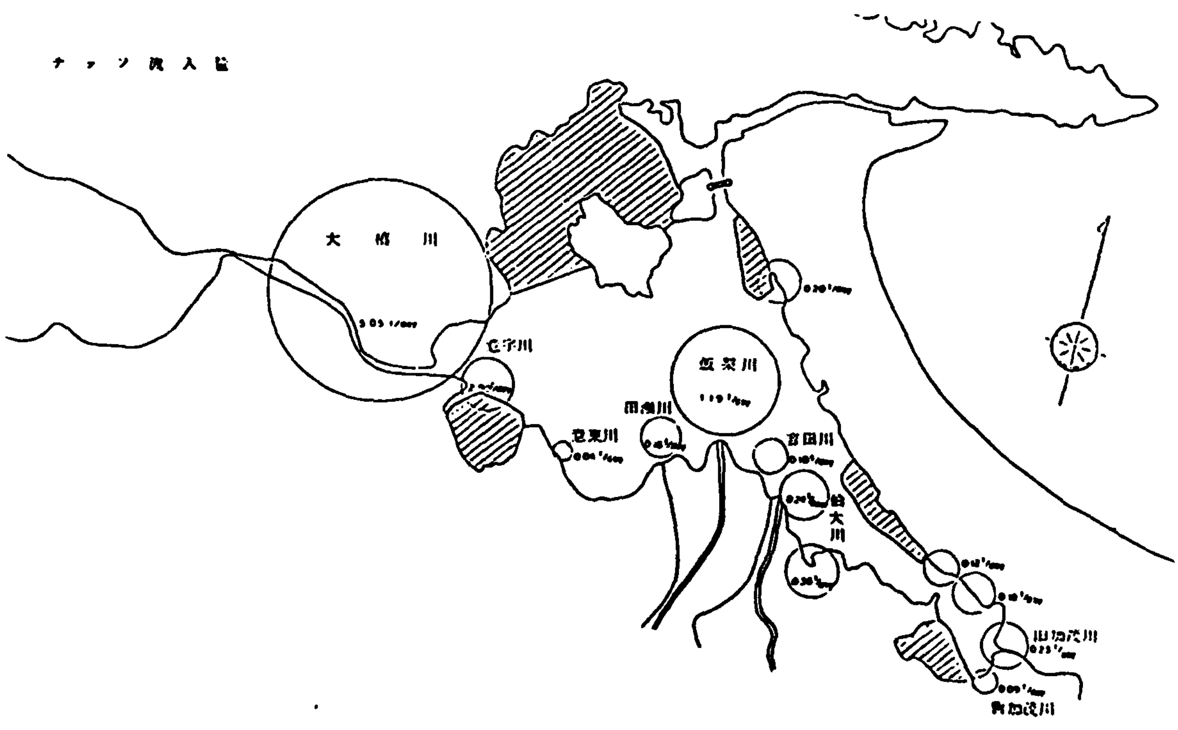


Fig. 19 Influx of T - N

Table 1 Removal Criteria

	General Pollution Indexes								
	COD >15–20 mg/g		I.L. >15%		Sulfide >1 mg/g		O_2 Consumption Rates	Release Rates of Nutrients	Finally Evaluated
Black	36.6	X	16.0	X	$4 \sim 8$	X	X	X	X
Black -gray	30.0	X	12.6	0		X	X	X	X
Gray	16.3	0	8.7	0	<1	0	0	0	0
Pale gray	7.5	0	4.5	0		0	0	0	0

X - should be removed
0 - does not have to be removed

during and after dredging. Few nutrients might be released from the dredged area. On the other hand, the inflowing pollutants are always settling and accumulating on the undredged as well as the dredged area. From these, release of nutrients might also occur. The question then arises that no great effects from dredging might be expected.

On the other hand the released quantities from such thin layers should be negligible because the released quantities are in proportion to the quantity of pollutants contained in sediment. Therefore, the effects of sediment removal should be evaluated accordingly.

The second question concerns freshwater conversion. If the present brackish water will be converted to fresh water by the interception of seawater, the strong saline stratification will vanish and water will mix vertically much more easily. As a result, the oxygen-rich water

will move down and the water quality would be better. Furthermore, since the oxygen environment would be improved from anoxic to oxic, it could be expected to reduce the release of phosphorus and to remove the causes of eutrophication.

But regarding such an opinion, the following points should be considered.

(1) After the freshwater conversion is finished, would blue algae generate to an enlarged scale?

As the present water is brackish, red tides occur now. It is presumed that salinity suppresses the crops of plankton. If the water becomes fresh, it is supposed that new plankton might generate on a large scale.

(2) In reality, will the sediment become oxic and will the release of phosphorus be reduced? This problem is concerned with the mechanism of phosphorus release. At the sediment surface two forces are acting, that is, (1) the deoxygenating action of the sediment and (2) feeding of oxygen from the upper layers. If the former would be larger than the latter, the anaerobic condition might be stable. It is principally determined by the deoxygenation of sediment and is independent of the DO conditions of water. If that is the case, the release of phosphorus from sediment might be diminished. This problem needs to be studied in more detail.

7. Conclusions

As mentioned before, Lake Nakanoumi is highly eutrophicated,

especially polluted by phosphorus. Now we stand at an important stage in protecting its environment and, furthermore, restoring it. The Izumo Office is studying this problem and working out a clean-up plan, which is based on sediment removal. Among the technical points, release mechanism is most important. Since the effects of dredging depend upon it, the dynamics of phosphorus are now being studied in detail. Besides, there is a special problem--the conversion from brackish to fresh water in Lake Nakanoumi. Therefore, the problems concerning it should be examined closely.

BOTTOM SEDIMENT IMPROVEMENT EFFECT ON WATER QUALITY
- EFFECT OF DREDGING AND CLEAN SAND LAYOVER -

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Summary

It is said that eutrophication in the closed sea is mostly due to nutrient load from the hinterland along with the released load from the sediment mud. Measures are being taken against the inflowing load under various laws and regulations, but no effective countermeasure has been found for curtailing the released load from the sediment mud. Henceforth, the Extensive Bottom Sediment Improvement Project is being planned by the Ministry of Transport in order to curtail the released load by improving bottom sediment. A follow-up investigation on the effect of environmental improvement was conducted by performing small-scale experimental works on the bottom sediments improvement at Osaka Bay and Hiroshima Bay as the basic study for the Project. About a half year after the experiment was performed, the following effects were confirmed:

1. Decline in the rate of release of COD, T-P, etc., from the sediment mud.
2. Decline in oxygen consumption rate by the sediment mud.
3. Improved quality of the interstitial water.
4. Increase in population and number of species of benthic organisms in the sand layover.
5. Decline in the number of bacteria and sulfate reducing bacteria on the sediment surface.

1. Introduction

The bottom sediment improvement project was studied in order to prevent pollution caused by eutrophication in the Seto Inland Sea. To assess the improvement of the surrounding environment expected when the

bottom sediment is cleaned, the follow-up investigation on the effect of the project has been performed by conducting small-scale experimental works at Osaka Bay and Hiroshima Bay. This report discusses decline in concentration of sediment and interstitial water quality, recovery of benthos, and the reduction effect of released nutrients obtained 6 months after the works.

2. Pollution in the Seto Inland Sea

Pollution in the Seto Inland Sea is characterized by the unique phenomena observed in respect of the closed inland sea pollution: eutrophication in the red tide which occurs extensively and chronically, high concentration of organic mud pollution occurring in the locally closed waters surrounded by the breakwaters, and floating garbages and oil balls on the water surface. Eutrophication is the most serious matter with which the Seto Inland Sea is faced and the solution to this problem is considered to be the key to bringing the Inland Sea back to its normal state. Fig. 1 shows the red tide occurrences in the Inland Sea in 1979.

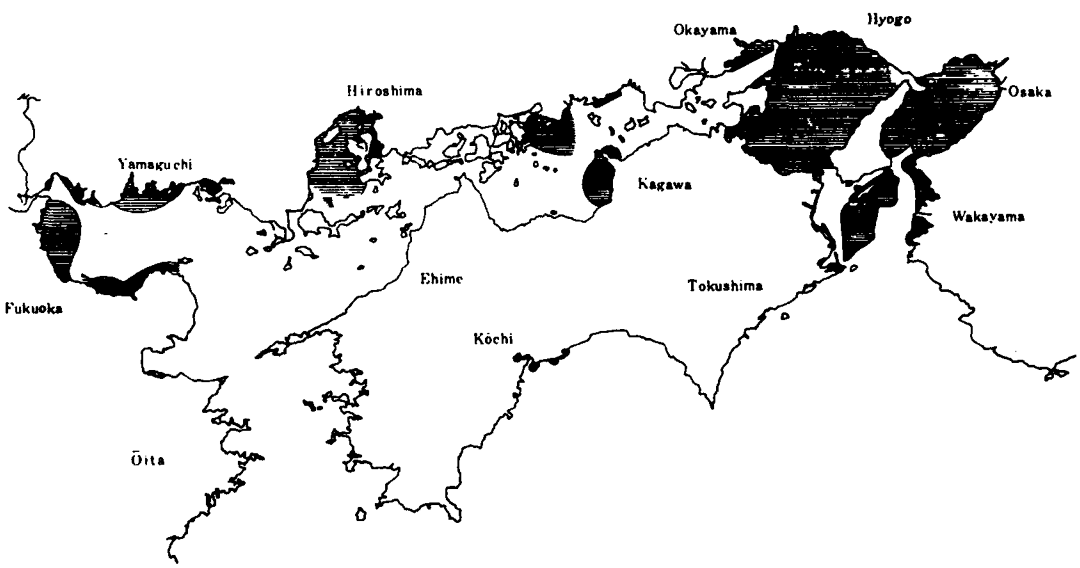


Fig. 1: Area where Red Tide Occurred in 1979

(Note): from "Red Tides in Seto Inland Sea" (in Japanese) compiled by Setonaikai Fisheries Coordination Office

3. Mechanism of Red Tide Occurrence in Seto Inland Sea

Generally, organic matters tend to remain on the sediment mud without becoming decomposed in the shallower closed waters as the Seto Inland Sea, and actually accumulation of organic matter is often found there.

Organic sedimentation in the mud decomposes and consumes the dissolved oxygen in the bottom layer of the water. Especially during the summer, the vertical mixing of the seawater is prevented by stratification and decomposition of the organic matter is accelerated as the temperature rises, thus consuming the dissolved oxygen and making the bottom layer of the water anaerobic. Fig. 2 shows the progress of the anaerobication in the bottom layer of the water during summer in Osaka Bay. As it is shown, the nutrient outflow is accelerated from the sediment mud due to the anaerobic bottom water and the bottom water becomes enriched (Fig. 3). Then, when the water mass is mixed, a phytoplankton bloom occurs.

A simplified cyclic mechanism of substances is presented in Figure 4. The large influx of organic matter results in poorer water quality. This is also known from the fact that the water quality improvement doesn't appear to be sufficiently effective though the inflowing load in the Seto Inland Sea declined largely during the past few years (Fig. 5). As it was described here, it can be considered that the Red Tide occurs chronically in the Inland Sea through the above-mentioned mechanism.

Taking into consideration the cycling of nutrients in the marine ecosystem, a heavy load of released nutrients from sediment mud is thought to enhance the eutrophication, and this is described in the simplified diagram of Fig. 6. According to the rough estimation in the Osaka Bay (1976), the amount of phosphate inflow from the area is 21.28 t/day which is almost equal to the outflow from the sediment of 19.0 t/day.

4. Guide to Extensive Bottom Sediment Improvement Project

As for the reduction of organic and nutrient flowing loads, halving of COD flowing load related to the industrial wastewater was achieved

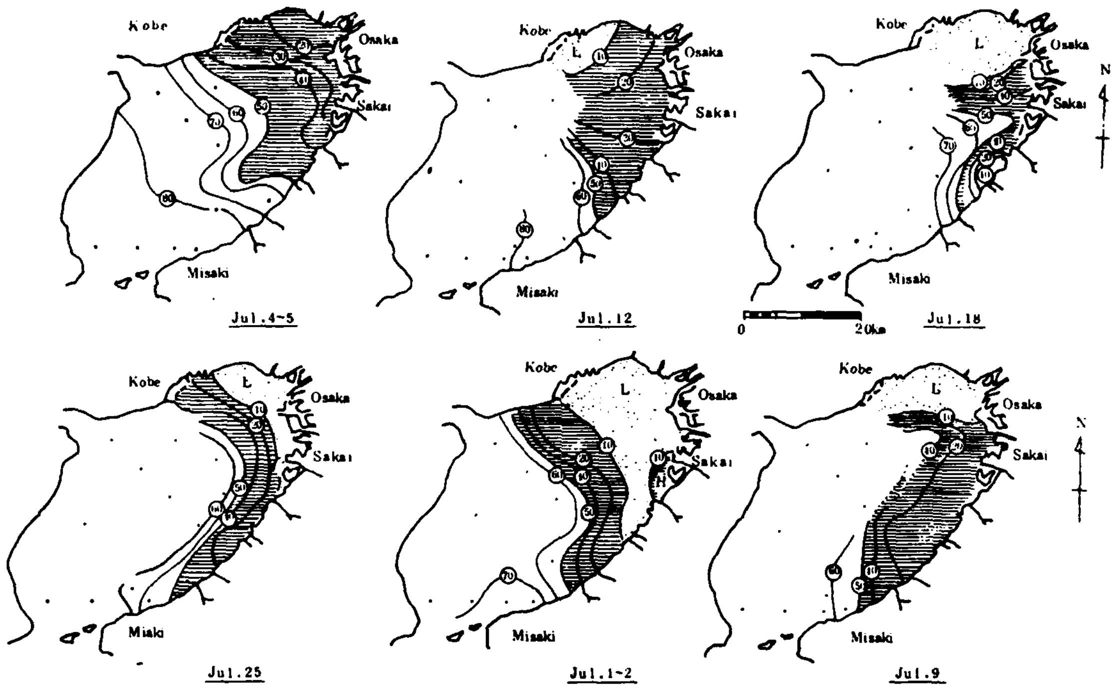


Fig. 2: Appearances of Anaerobic Water Mass in Osaka Bay (bottom layer)

*unit % (percentage of dissolved oxygen saturation)

(Note): From Osaka Fisheries Experimental Station Data

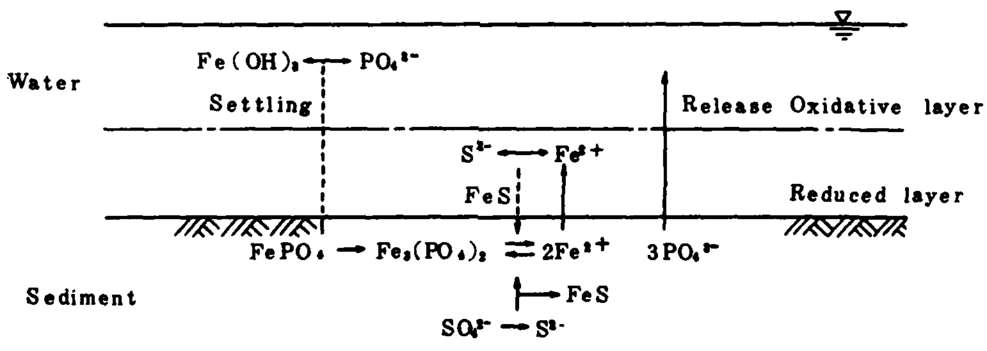


Fig. 3: Transformation of Phosphate in Reduced State of Sediment Mud

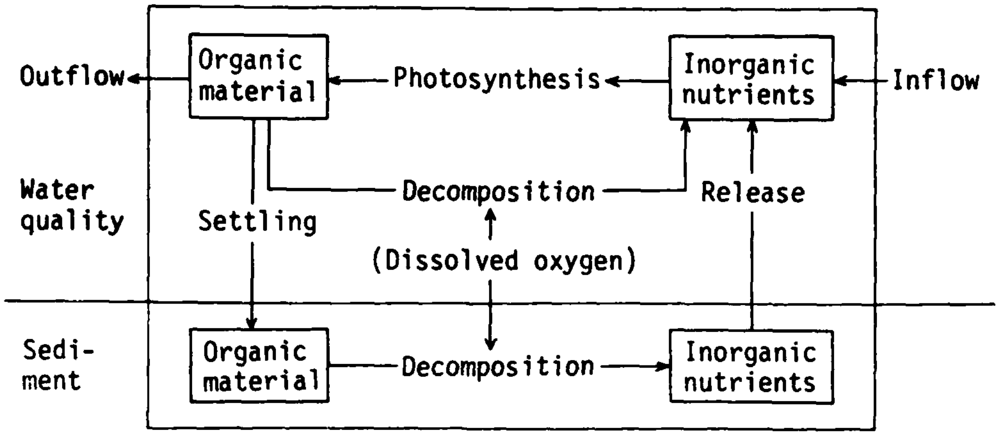


Fig. 4: Simplified Model of Material Cycle

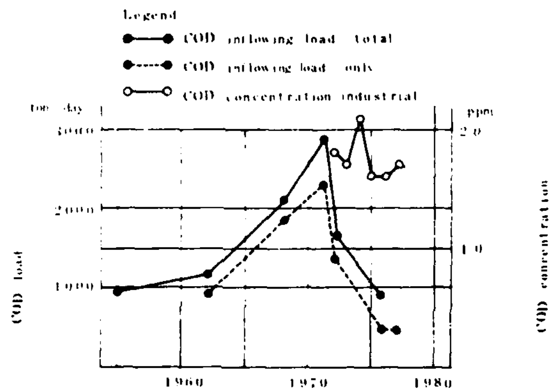


Fig. 5: COD Inflowing Load and COD Concentration in the Seto Inland Sea

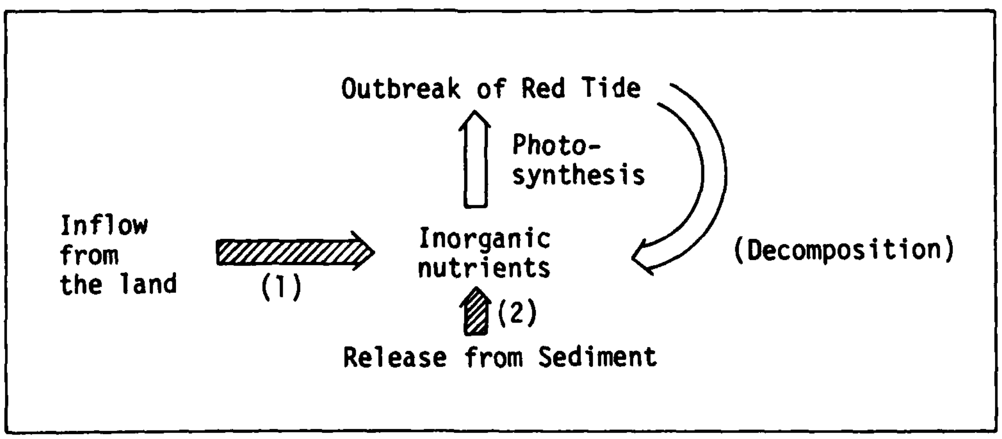
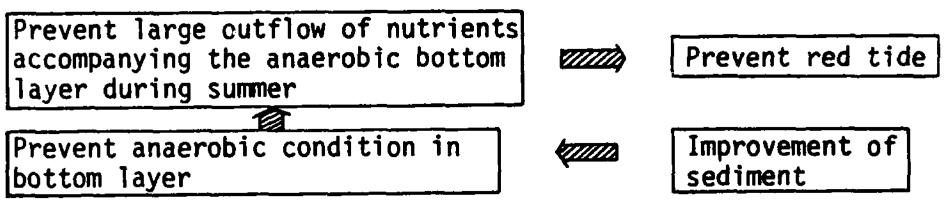


Fig. 6: Autochthonous Organic Matter

through the Interim Law for Conservation of the Environment of the Seto Inland Sea (June, 1973), and the works to control total COD flowing load including urban runoffs together with reduction of phosphate, implemented under the Special Law for Conservation of the Environment of the Seto Inland Sea (June, 1978) which is a successor to the above Law. On the other hand, it is necessary to destroy the cycle of nutrient flow via sediments in order to cut down the release load of nutrients. Thus, the Extensive Bottom Sediment Improvement Project has been planned.

The eutrophic pollution will be prevented and a normal balance of marine ecosystem recovered by a systematic enforcement of these countermeasures.

The objective of the project is shown in the diagram below:



As it is shown above, the object of this project is to try and regain the ocean's own self-purification ability by preventing release of nutrients from the sediment mud and anaerobic condition in the sediment.

The measures conceivable to prevent release of nutrients from the sediment mud are removal (dredging) of super nutritious sediment mud and separation of the sediment from the seawater (clean sand layover). Since the field survey to confirm these effects has not been achieved so far, the follow-up investigations have been conducted on the effect of the environmental improvement through small-scale experimental sediment cleaning works in Osaka Bay and Hiroshima Bay which are the most heavily polluted areas in the Inland Sea. The interim results of these experiments are discussed below.

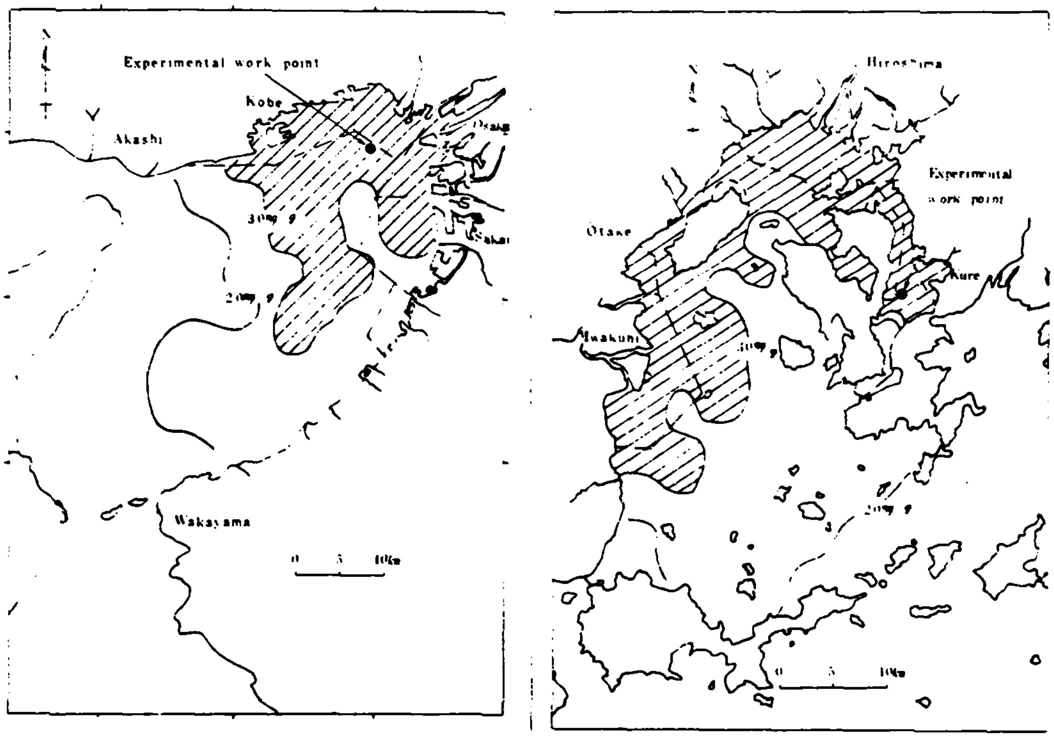
5. Outline of Experimental Works

Experimental works have been performed in Osaka Bay and Hiroshima Bay at the dotted point in Fig. 7: dredging in Osaka and sand layover in Hiroshima. Investigations for secondary pollution such as turbidity caused by the experimental works have also been conducted.

A summary of the experimental works of 1979 and 1980 is shown in Table 1.

6. Outline of Follow-up Investigation

To evaluate the effect of environment improvement achieved by the sediment improvement works, decline in released nutrients and organic matter in sediment, decrease in oxygen consumption, and recovery of



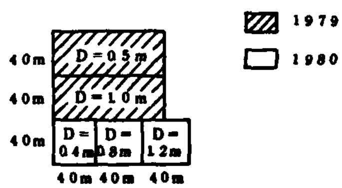
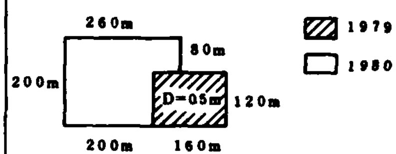
Osaka sediment quality, COD distribution (Oct. 1979)

Hiroshima sediment quality, COD distribution (Oct. 1979)

Note: Analysis made based on "Guideline for Water Pollution Survey" (ed. by Japan Fisheries Resource Conservation Association)

Fig. 7: Experimental Work Point

Table 1: Outline of Experimental Works

Bay / Item	Osaka Bay		Hiroshima Bay	
	1979	1980	1979	1980
Point of works	Off Nishinomiya Break-water (-16 m)		Kure District, Ohgaki area (-21 m)	
Period of works	March, 80	August, 80	Oct.-Nov. 79	July-Aug.,80
Description of works	Dredging 0.8 ha (100x30m) Dredging depth 0.5m, 1.0m	Dredging 0.48 ha (120x40m) Dredging depth 0.4m, 0.8m, 1.2m	Sand layover 1.92 ha (120x160m) Layer thick-ness 0.5m	Sand layover 4.48 ha (200x200m +80x60m) Layer thick-ness 0.3m
Type of working crafts used	Special pump dredger	Special pump dredger	Conveyor (2000 m^3)	Unloader (260 m^3/h)
Type of sands used	-	-	Sea sand	Sea sand
Area of works				

organisms have been studied through the follow-up investigation. On the effect of controlling the released volume of the nutrients and oxygen consumption, the test equipment shown in Fig. 8 was set up in and outside the experimental work areas in order to record the chronological changes of the water quality within the equipment. The schedule of the follow-up investigation is shown in Table 2.

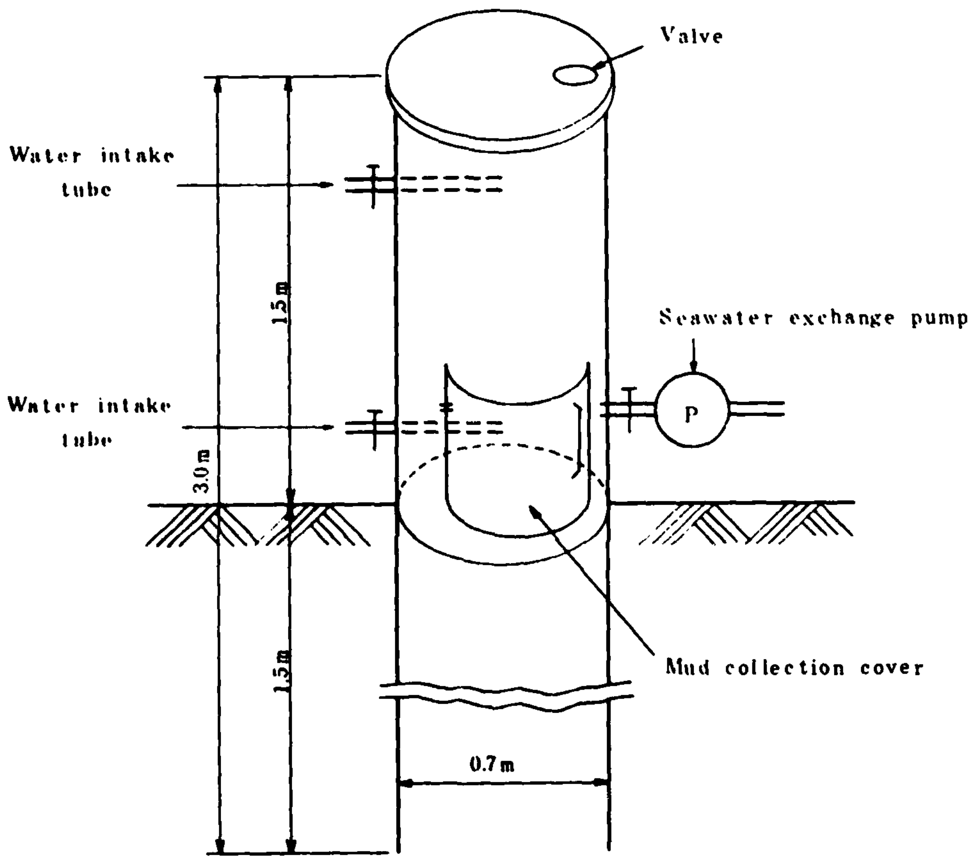


Fig. 8 Schematic Drawing of Device Used for Released Load Tests

Description of the Investigation

*Experiments on Release and Oxygen Consumption

...... Investigate the changes in oxygen consumption occurring in the decomposition of the organic matter in sediment and amount of released nutrients and organic

Table 2: Schedule for Experimental Works and Follow-up Investigation

	'79					'80						
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.
Osaka Bay							P.I.	Dredge		1st		2nd
Hiroshima Bay			P.I.	Lay-over	1st		2nd				3rd	

	'80					'81		
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Osaka Bay	Dredge	1st			2nd		3rd	
Hiroshima Bay	Lay-over	1st		2nd			3rd	

P.I.: Preliminary Investigation
1st : 1st Post-work Investigation
2nd : 2nd Post-work Investigation
3rd : 3rd Post-work Investigation

matter from the sediment after the experimental works. Field survey and indoor experiments have been conducted.

*Water, Sediment Quality, and Interstitial Water Quality

...... Investigate changes in the water quality, sediment quality, and interstitial water quality caused by the experimental works.

*Deposit

...... Investigate conditions of newly accumulated organic matter after the experimental works.

*Benthic Organisms, Bacteria, and Sulfate Reducing Bacteria

...... Observe changes in biotic environment caused by the experimental works.

*Video Film

...... Observe changes of the sediment surface, etc., made by the experimental works through underwater video films.

*Sand Layover Thickness (Hiroshima Bay only)

...... Investigate chronological changes in the layover depth.

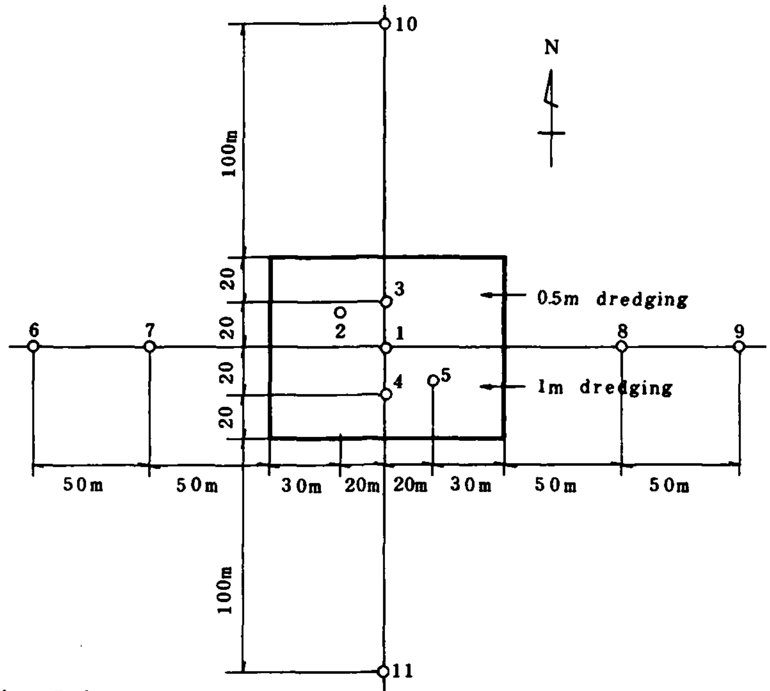
At this time, we report the outline of the summarized results of the two post-work investigations by July 1980 for Osaka Bay and the two post-work investigations by February 1980 for Hiroshima Bay.

7. Results of Investigations at Osaka Bay

Investigation points and periods are shown in Fig. 9. Summary of the results of investigations in February (preliminary investigation), May (1st post-work investigation), and July (2nd post-work investigation) 1980 are described below.

(1) Field Experiments on Released Load

By using the setup shown in Fig. 8, the measurement of released load from the sediment was taken. The tests were conducted for 10 days for the preliminary investigation and for 20 days for each post-work investigation.



Investigation Points

Items for investigation	Feb.(preliminary)	May & July
Release test (field)	2,2',6,6'	2,2',5,6,
Control test (field)	1,1'	1'
Release test (indoor)	2,6	6 (July)
Water quality	1,2,5,6,9	2,5,6
Sediment quality	1,2,5,6,9	2,5,6
Interstitial water quality	2,6	2,5,6
Newly accumulated sediment	1	1
Benthos	1 ∿ 11	1,2,5,6,9,10,11
Bacteria, sulfate reducing bacteria	2,6	2,5,6
Oxygen consuming test	2,6	-

Note: Field experiments on released load show the stations where pipes with covers are set up.

Fig. 9: Measurement Network for Follow-up Study and Period of Investigation

Experiment conditions can be divided into six categories according to

(1) presence or absence of sediment mud effect,

(2) dredged or undredged,

(3) presence or absence of deposits.

The absence of the effect of sediment as mentioned in (1) means that the overlaying water does not contact the sediment mud within the equipment because of a partition inside the equipment. Hence, this is a control experiment examining the changes of the seawater only. The experiment was conducted at Station 1. Dredged or undredged as mentioned in (2) means whether it is inside the dredging area or not. Station 2 and 5 in the post-work investigations are within the dredged area and station 6 is outside. The presence or absence of the newly produced deposits mentioned in (3) means that whether the cover is put on (presence of cover, thence no effect on the newly produced deposits), or the cover is left off (no cover, there is an effect of the newly produced deposits) during the period from the time the equipment is set on the sea bottom until the test is started. *Table 3 shows* conditions for the test equipment setup.

Table 3: Conditions of the Test Equipment Set Up

	Condition \ St. No.	1		2		5		6		Total
	With/without cover	w/	w/O	w/	w/O	w/	w/O	w/	w/O	
February	Sediment mud condition	Control		Sludge		Sludge		Sludge		6
	Equipment provided	*	*	*	*			*	*	
May & June	Sediment mud condition	Control		0.5m dredge		1m dredge		Sludge		5
	Equipment	*		*	*		*		*	

The rates of release were calculated through the chronological changes in the water quality in the post-work investigation, and were compared with those of inside and outside the dredged area. The results are shown in Tables 4 and 5. In the first post-work investigation, COD, T-P, and T-N are thought to be showing the effect of release reduction by dredging through the comparison of the rates of release from inside and outside the dredged area. In the 2nd post-work investigations, effect of release reduction was observed in COD and T-P, but not in T-N. The rate of oxygen consumption showed smaller values in the dredged area in both of the two post-work investigations.

No difference in release rate with or without the newly produced deposits was found in this experiment.

Fig. 10 shows the relationship between rate of T-P release and DO. A straight line in the graph is considered to be the maximum values of the rate of release at respective DO. It is also found that recovering DO in the bottom layer of the water is necessary to control the release of phosphate.

Table 4: Mean rate of release (comparison outside & inside the dredged area (May))**

Items	Dredged area (mean of st. 2 & 5)	Undredged area
DO* (mg/m^3day)	34	59
COD (")	-56	110
T-P (")	1.0	4.1
PO_4-P ( )	0.8	1.4
T-N (")	-6.6	38.0
NH_4-N ( )	1.0	5.1
NO_2-N (")	0	0.6
NO_2-N (")	-0.3	-1.0
TOC (")	-220	-49

* shows rate of oxygen consumption

** Values obtained are those from which the control values have been deducted.

Table 5: Mean rate of release (comparison outside & inside the dredged area (July))***

Items	Dredged area (mean of st. 2 & 5**)	Undredged area (St., 6)
DO* (mg/m^3day)	15	30
COD (")	435	472
T-P (")	15.7	21.4
PO_4-P (")	15.3	21.5
T-N (")	131.2	106.5
NH_4-N (")	-1.9	13.5
NO_2-N (")	-4.7	-2.8
NO_3-N (")	9.7	10.5
TOC (")	37.5	75.0

* shows rate of oxygen consumption

** station 2 with cover was removed due to variation in data

*** Values obtained are those from which the control values have been deducted.

(2) Sediment Quality

Comparison of sediment surface layers outside and inside the dredged area in the post-work investigation has been made and the results are shown in Figs. 11 and 12. Concentration is lower for all items in the dredged area, especially that of sulfide. This is attributed to the fact that sediment surface layer within the dredged area is maintained in an oxidative condition as is clear through the comparison of redox potential (Eh).

The difference of the values between the dredged area and the undredged area in the second post-work investigation is smaller compared to the first one. This can be considered to be due to the inflow of sludge from the undredged area to the dredged area and the sedimentation of newly produced accumulation.

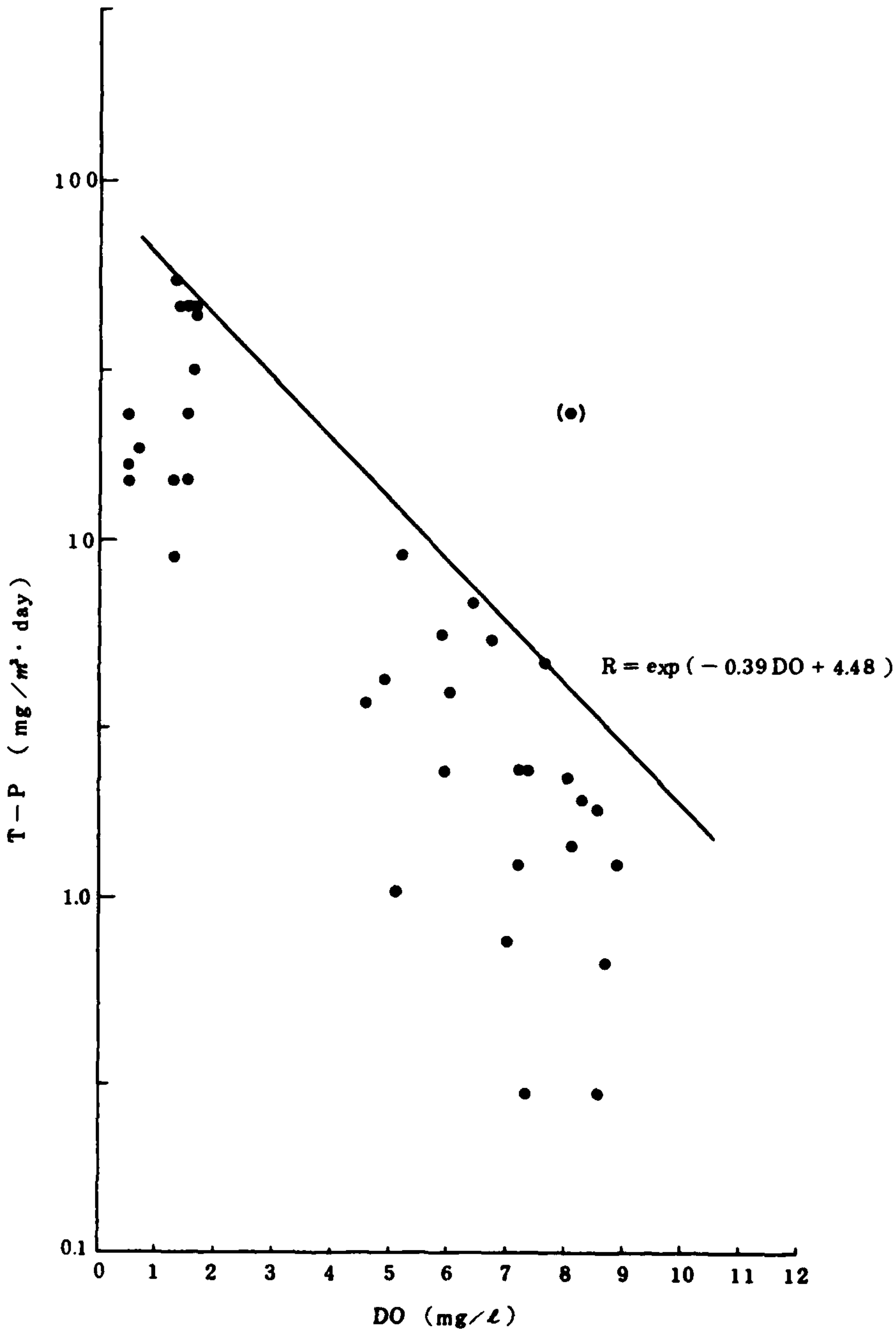


Fig. 10: DO in overlying water and rate of T-P release rate

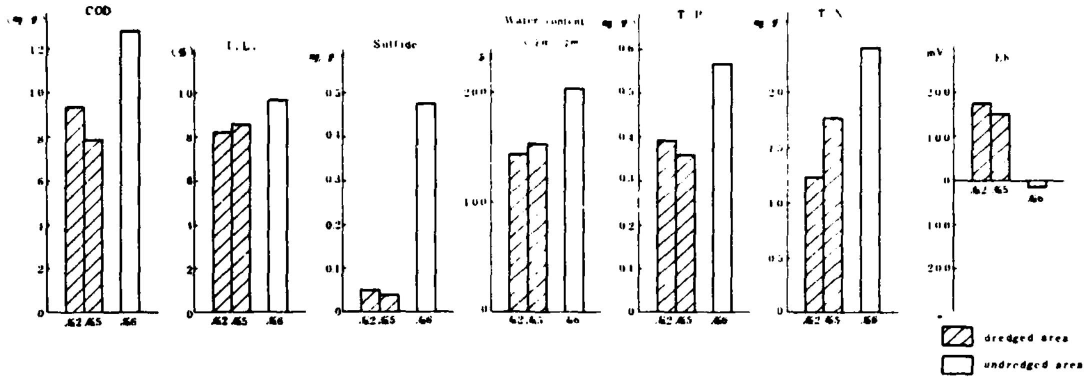


Fig. 11: Comparison of Sediment Surface Types Inside and Outside the Dredged Area (1st post-work investigation)

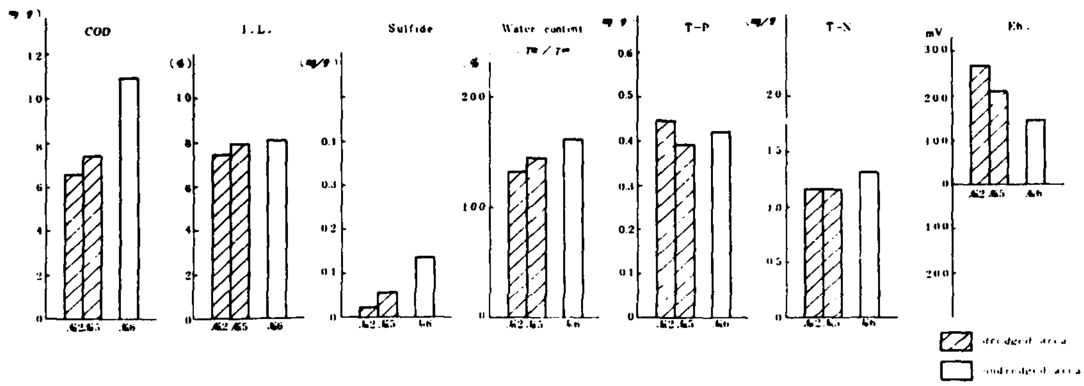


Fig. 12: Comparison of Sediment Surface Types Inside and Outside the Dredged Area (2nd Post-Work Investigation)

(3) Interstitial Water Quality

Vertical distribution of phosphate in the interstitial water inside and outside the dredged area in the post-work investigation is shown in Fig. 13.

It is said that nutrients within the sediment mud are released to the overlying water through the interstitial water. Thus, to learn the concentration of the interstitial water, it is necessary to study the rate of release. Higher values are found in the 3- to 9-cm layer inside the dredged area through the investigation conducted in May, but the values are higher throughout the whole layer outside the dredged area through the July investigation.

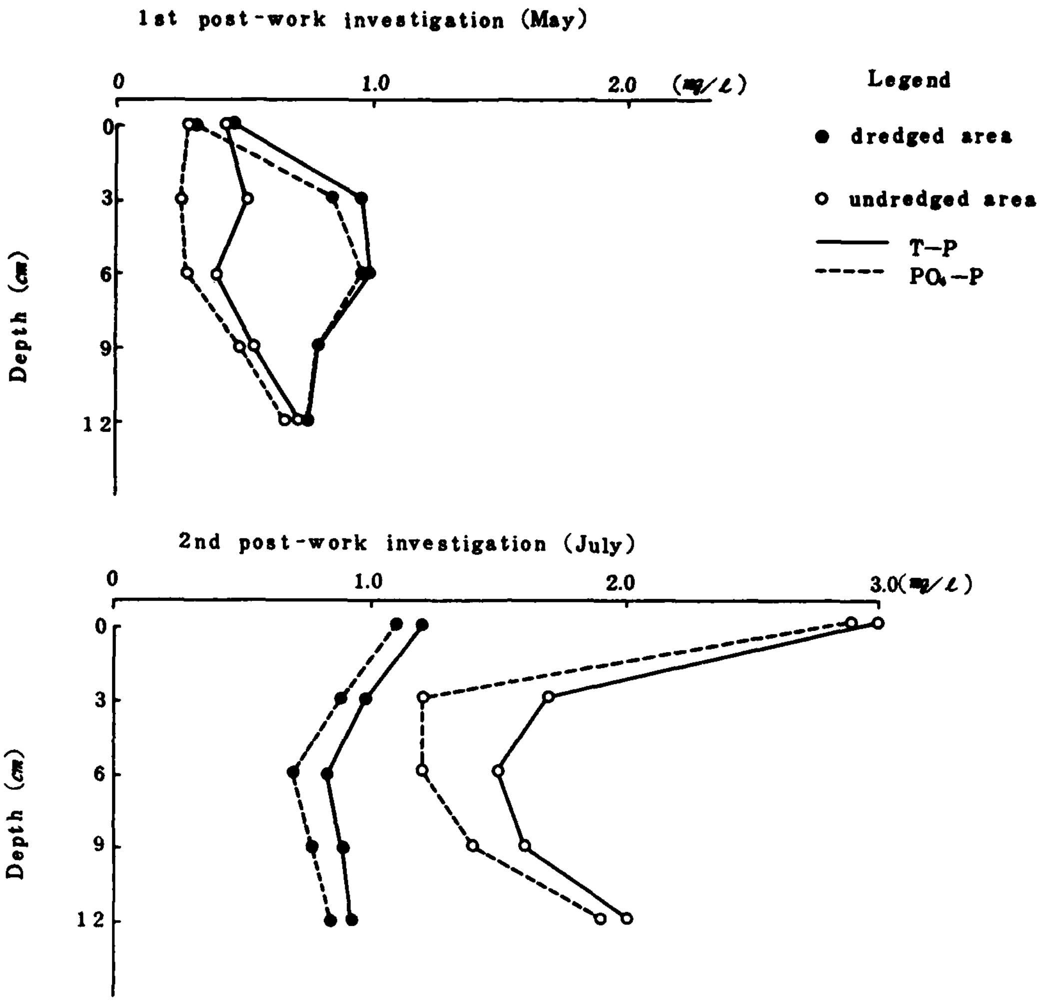


Fig. 13: Vertical Distribution of Interstitial Water T-P, PO_4-P

(4) Benthos

Surface mud of sediment was collected, and screened benthos were determined using 1-mm meshes and 0.5-mm meshes from 11 stations (Stations 1 to 11) in February, and from 7 stations (Stations 1, 2, 5, 6, 9, 10, and 11) in May and July. Average values in all stations were: 1271 individuals per square meter in February with 29 species and polychaeta percentage composition of 97.3%; 1375 individuals per square meter with 45 species and polychaeta percentage composition of 71.0% in May; and 3261 individuals per square meter with 39 species and polychaeta

percentage composition of 97.8% in July. Number of populations is almost equal in February and May, but it almost doubles in July. Number of species is small in February but it is increased in May and July. Polychaeta percentage composition is also small due to increase of Mollusca in May, but the values are over 90% in other periods. Compared results of the number of population in the dredged area and the undredged area are shown in Fig. 14. When the two areas are compared, the number of animals is larger in the undredged area than in the dredged area and the value almost triples in the July investigation. This is due to a large increase of polychaeta.

Fig. 15 shows the chronological change of Prionospio pinnata and Theora lata which serve as the indicators of pollution and which are the major species of the investigation points. Prionospio pinnata decreased in May and increased in July. The number is greater outside the dredged area than inside the dredged area. On the other hand, Theora

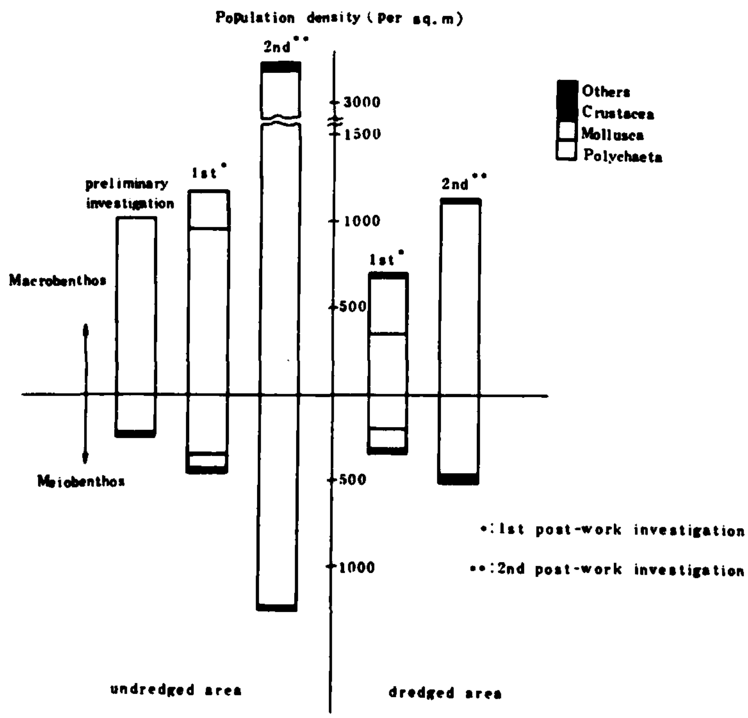


Fig. 14: Mean Population Density of Benthos (per sq. m)

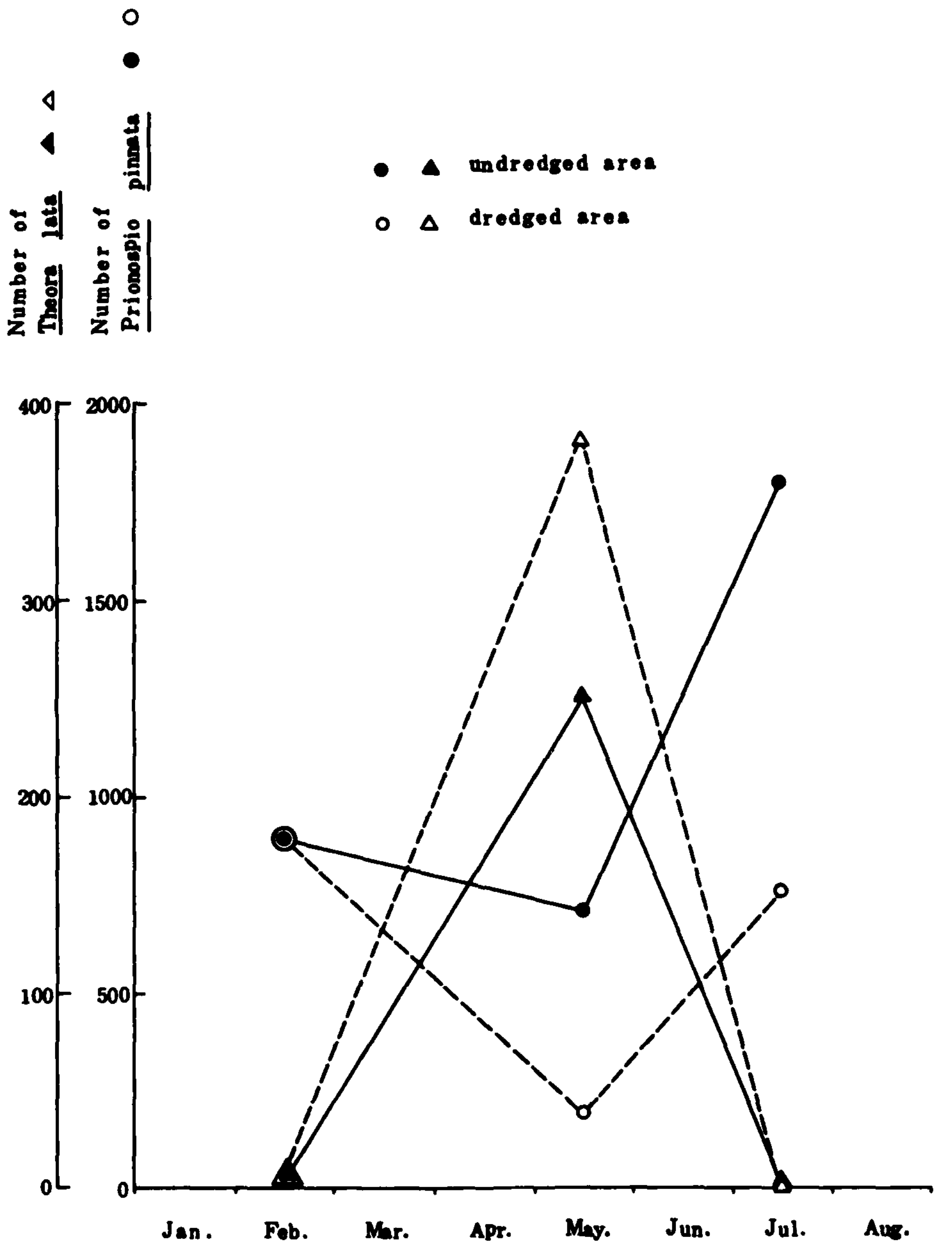


Fig. 15: Change in Organism Populations

lata increased in May and disappeared almost completely in July. The major part of the increase in mollusks in May is by Theora lata.

(5) Bacteria

Results of bacteria investigation in the sediment surface mud in the dredged area and the undredged area are shown in Fig. 16. Both bacteria number and sulfate reducing bacteria are low in the dredged area compared to the undredged area.

(Note: 1) Significance of Bacteria Number Test

The bacteria number experiment indicates the total number of bacteria including various types of aerobic bacteria and anaerobic bacteria that are cultured within the medium defined by the experiment method, and the value becomes larger as pollution caused by organic matter becomes accelerated.

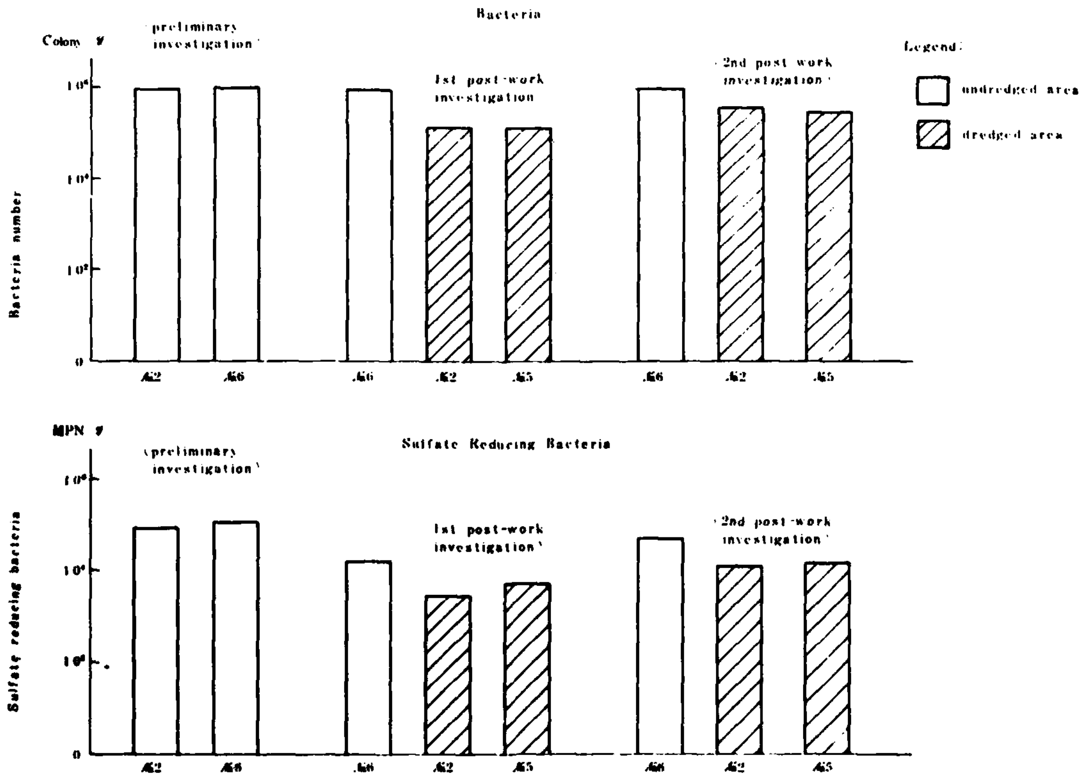


Fig. 16: Results of Bacteria Investigation

(Note: 2) <u>Significance of Sulfate Reducing Bacteria Number Test</u>

Sulfate reducing bacteria is absolute anaerobic bacteria that gains the energy by oxidizing organic matter using oxygen in the sulfate salt in anaerobic condition. During this process the sulfate is reduced to hydrogen sulfide. Produced hydrogen sulfide corrodes metals and concrete, thereby damaging organisms and plants in the water directly or indirectly and generating odors, .etc.

(6) Conclusion

The results of the preliminary investigation (February), the 1st post-work investigation (May), and the 2nd post-work investigation (July) are summarized as follows.

(a) Decline in the rate of release for COD, T-P, and T-N was observed, but the value for T-N release rate increased in the 2nd post-work investigation.

(b) Decline in the rate of oxygen consumption was observed.

(c) Decline in the concentration of organic matter and nutrients, particularly of sulfide, on sediment due to dredging was observed. But the difference between the dredged area and the undredged area became smaller in the 2nd post-work investigation.

(d) Concentration in interstitial water declined during the summer season.

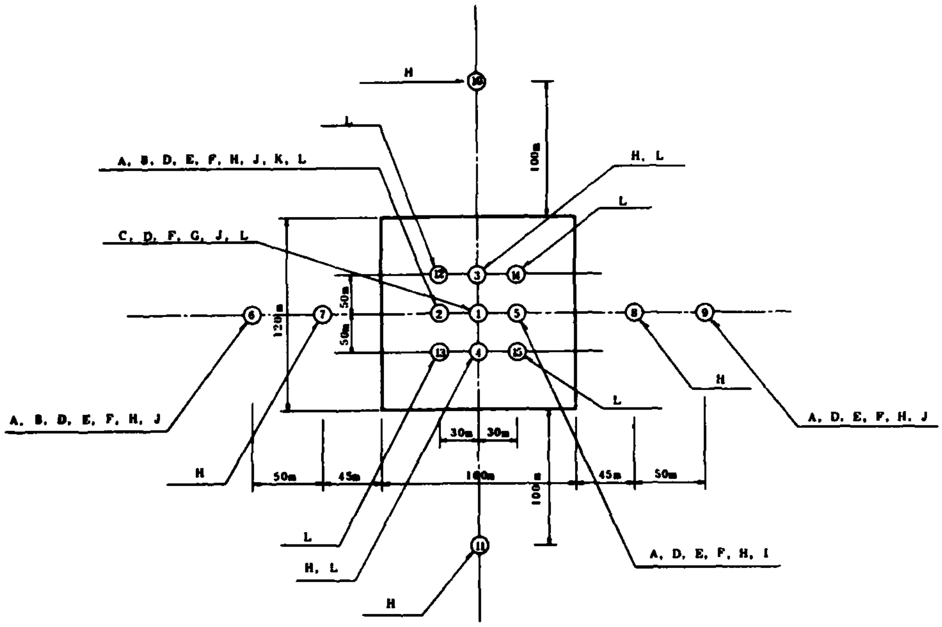
(e) In respect to benthos, a large population was found in the undredged area. Increase in number of polychaeta was particularly remarkable.

(f) Both number of bacteria and sulfate reducing bacteria declined.

8. Results of Investigation at Hiroshima Bay

The results of the preliminary investigation of October 1979, the 1st post-work investigation of December 1979, and the 2nd post-work

investigation of February 1980 are discussed herein. Investigated stations are shown in Fig. 17 and the investigation period in Table 6.



Legends:

A: release test (field)
B: release test (indoor)
C: control test
D: water quality
E: sediment quality
F: interstitial water quality
G: newly accumulated sediment
H: benthos
I: video photography
J: bacteria, sulfate reducing bacteria
K: oxygen consuming test
L: layover thickness measurement
□: layover area

Fig. 17: Measurement Network for Follow-up Study

(1) Field Release Load Experiment

For the field release experiment, the apparatus shown in Fig. 8 was set up and the released volume from the sediment mud was measured during a period of 5 days in the preliminary investigation, 20 days in the 1st post-work investigation, and 5 days in the 2nd post-work investigation. Six cases were set as an experimental condition similar to the investigation conducted in Osaka Bay. Table 7 shows the conditions of the experimental equipments.

Table 6: Points and Period of Observation in the Follow-up Investigation

Items investigated	Station numbers	Number of stations	Number of layers	Observation period			Remarks
				Oct. 1979	Dec., 1979	Feb. 80	
				Immediately before work	Immediately after work		
Release test (field)	2, 5, 6, 9	4	1 (surface layer)	2 points (2, 6)	4 points	4 points	
Control test (field)		1	1 (surface layer)	1	1	1	
Release test (indoor)	2, 6	2	1 (surface layer)	2	2	2	
Oxygen consuming test	2, 6	2	1 (surface layer)	2	2	2	
Water quality	2, 6	5	1 (surface layer) [3 layers for station 1 (upper, intermediate, overlying)]	5	5	5	
Sediment	1, 2, 5, 6, 9	5	1 (surface layer) [5 layers for stations 2, 6 (immediately before work only)]	5	5	5	
Interstitial water	2, 5, 6, 9	4	1 (surface layer)	2 (2,6)	4	4	

(Table 6: Continuation)

Newly accumulated sediment	1	1	2 (1.5 m above sediment mud, & 1/2 water depth)	1	1	1	
Benthos	1, 2, 3, 4, 5, 6, 7, 8 9, 10, 11	11	1 (surface layer)	11	11	11	
Bacteria Sulfate reducing bacteria	2, 5, 6, 9	4	1 (surface layer)	2 (2,6)	4	4	
Video photography	A-A', B-B' C-C'	3 measurements	1 (surface layer)	5	3	3	
Thickness of layover	1, 2, 3, 4 5, 9, 12, 13, 14, 15		1 (surface layer)	-	Post-work, at 1 month intervals		

(Note) At stations 5 & 9, sediment mud was collected from the pipes, and analyses of sediments, the interstitial water, organisms, bacteria, and sulfate reducing bacteria were conducted.

Table 7: Conditions for Setting Experiment Equipments

	Station	1		2		5		6		9		
	with/without cover	w/	w/O	w/	w/O	w/	w/O	w/	w/O	w/	w/O	Total
October	Sediment mud condition	control		sludge		sludge		sludge		sludge		10
	Equipment provided	*	*	*	*	*	*	*	*	*	*	
Dec. & February	Sediment mud condition	control		sand		sand		sludge		sludge		10
	Equipment provided	*	*	*	*	*	*	*	*	*	*	

Chronological developments of relationship between PO_4-P and DO in the 1st post-work investigation are shown in Fig. 18. The rates of release were calculated through the chronological changes in the water quality and the results are shown in Table 8. The effect of the reduced release made by the clean sand layover appears to be obvious. However,

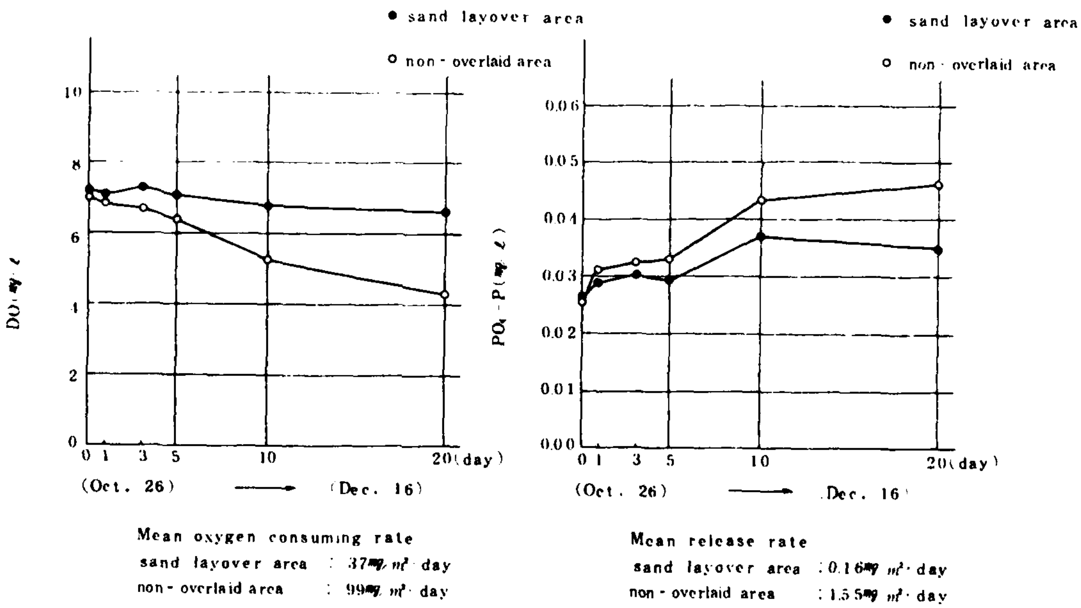


Fig. 18: Chronological Changes in Water Quality Observed in Field Release Test

Table 8: Mean Release Rate (1st Post-work Investigation)**

Items	Sand layover area (mean of No. 2 & 5)	Non-overlaid area (mean of No. 6 & 9)
DO* (mg/m^2d)	-	148
COD (")	-8	-29
T-P (")	0.06	1.0
PO_4-P (")	0.94	9.37
T-N (")	-0.94	9.37
NH_4-N (")	0.08	3.25
NO_2-N (")	0.22	2.25
NO -N (")	4.06	7.29
TOC (")	2	53

* shows rate of oxygen consumption

** Values obtained are those from which the control values have been deducted.

because the experimental result was obtained during the winter when the absolute values of the release rate is small, measurement during the summer season when the release rate becomes larger is necessary.

(2) Sediment Quality

Horizontal distributions of the sediment surface at the periods of the preliminary investigation and the post-work investigations are shown in Fig. 19. Either the low concentration or no value is observed for the surface portion after the layover work has been performed, indicating a remarkable difference from the non-overlaid area.

(3) Interstitial Water Quality

To study changes in interstitial water quality caused by the sand layover, comparison of the layover area and the non-overlaid area in the 1st postwork investigation was made and the results are shown in Fig. 20. In the investigation results, DO in the layover area is 2 - 4 times more than that of the non-overlaid area and COD, T-P, and T-N are

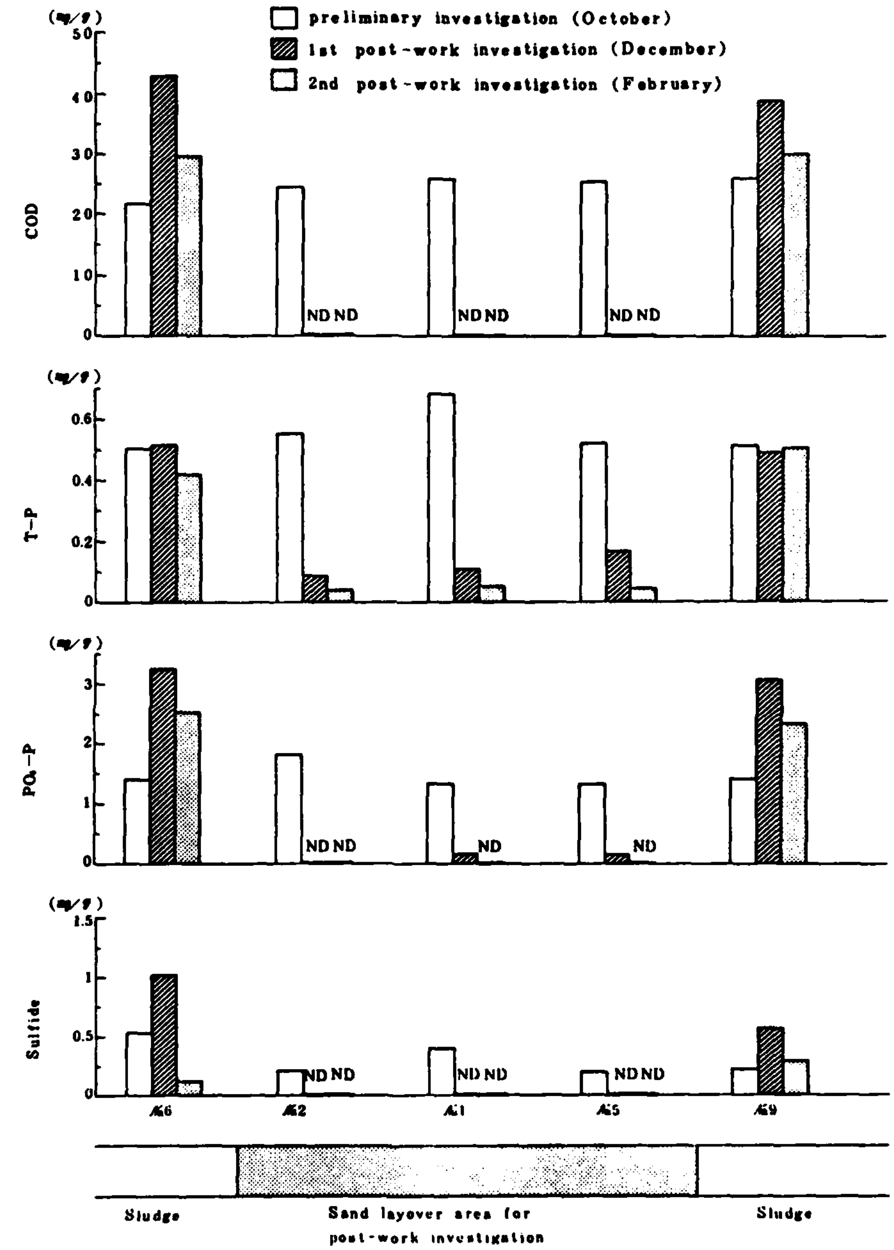


Fig. 19: Horizontal Distribution of Sediment Surface (preliminary investigation, 1st, 2nd post-work investigations)

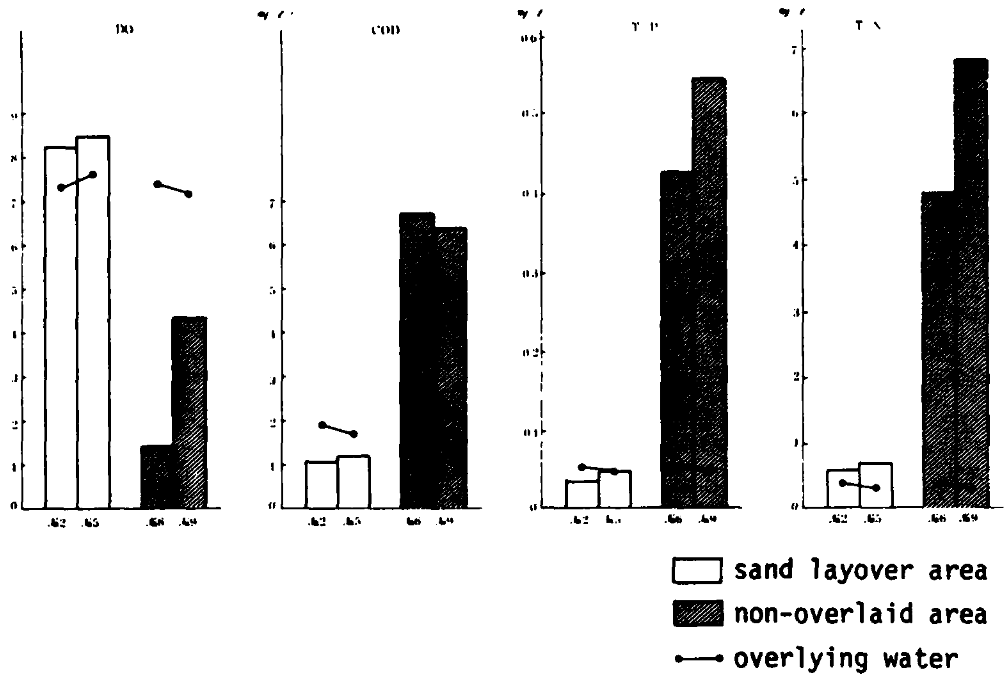


Fig. 20: Changes in Interstitial Water Due to Sand Layover and Comparison with Overlying Water (1st post-work investigation)

1/6, 1/10, and 1/8 of the values of the non-overlaid area, thus indicating a remarkable improvement of interstitial water quality at the non-overlaid area. The same inclination is seen in the 2nd post-work investigation results.

The concentration in the overlying water is shown in Fig. 20 for comparing with that of the interstitial water. Concentrations in interstitial water and in overlying water are almost equal at the sand layover area, but the concentration in interstitial water is higher than that in overlying water at the non-overlaid area.

Analysis of the interstitial water quality was conducted by collecting the sediment mud in the field release load test equipment after the field experiment was finished. Fig. 21 shows the existing form of nitrogen. The non-overlaid area was in an anaerobic state having almost no existing NO_2-N and NO_3-N, while the layover area showed the presence of NO_3-N, indicating that an aerobic state is maintained.

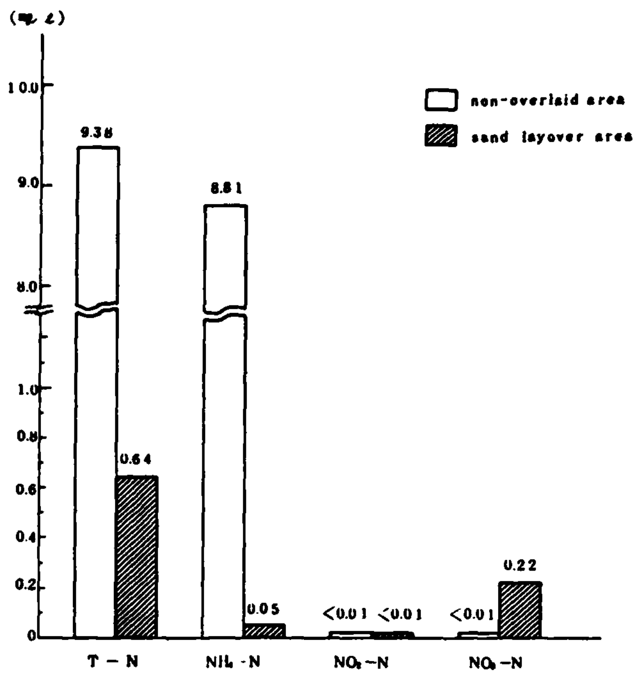


Fig. 21: Forms of Nitrogen in the Interstitial Water within the Field Release Load Test Equipment

(4) Benthos

The total number of benthic species that appeared in the preliminary, 1st post-work, and 2nd post-work investigations was 22 at the sand layover area and 20 at the non-overlaid area. The number of species increased in both areas in the 2nd post-work investigation over those in the preliminary and the 1st post-work investigations. The increase is considered to be a seasonal fluctuation.

Average population densities (per square meter) of benthos at the sand layover area and at the non-overlaid area are shown in Fig. 22. In the 1st post-work investigation, macrobenthos (over 1 mm) decreased sharply at the layover area, but meiobenthos (over 0.5 mm) increased. Decline of macrobenthos is considered reasonable because the investigation was conducted right after the sand layover. On the other hand, the number of meiobenthos is thought to recover quickly to its previous state even right after the sand layover because most of the larvae sink to the bottom to survive after the free-floating stage.

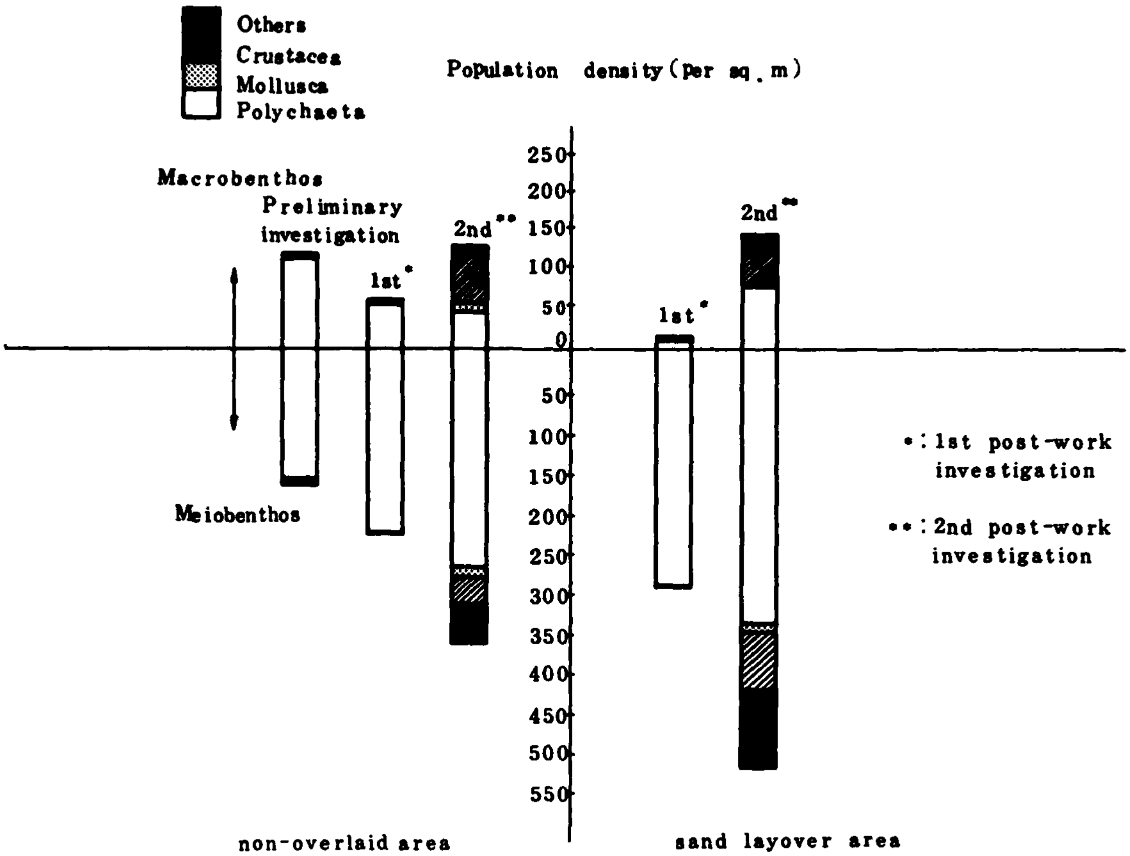


Fig. 22: Mean Population Density of Benthos

When the composition of the benthos was examined, the increase of crustaceans and other species in the 2nd postwork investigation was remarkable along with the increase of polychaetes, while polychaetes took an overwhelmingly large part of volume in both areas in the preliminary and the 1st post-work investigations.

Both the number of species and the population density tend toward a large increase which is considered to be a seasonal change, although it seems that the layover appeared to be more or less effective having a larger ratio of increase at the overlaid area. However, since the life cycle of most of these organisms is one year, it cannot be concluded until after the year has elapsed. Prionospio pinnata and Theora lata collected in a great number in Osaka Bay were scarce in Hiroshima Bay.

(5) Bacteria

Comparison of the bacteria investigations in the sediment surface in and outside of the overlaid area is shown in Fig. 23. Bacteria and sulfate reducing bacteria counts were fewer within the overlaid area than outside.

(6) Summary

The results of the preliminary investigation (October), the 1st post-work investigation (December), and the 2nd postwork investigation (February) are summarized as follows.

(a) The release rate of T-P, PO_4-P, T-N, and NH_4-N decreased at sand layover area in the field release experiment.

(b) COD, P, and N values in the sediment surface layer at sand layover area declined remarkably, thereby indicating the improvement in the sediment.

(c) Differences in the concentrations in the interstitial water and in the overlying water suggested a decrease in the release.

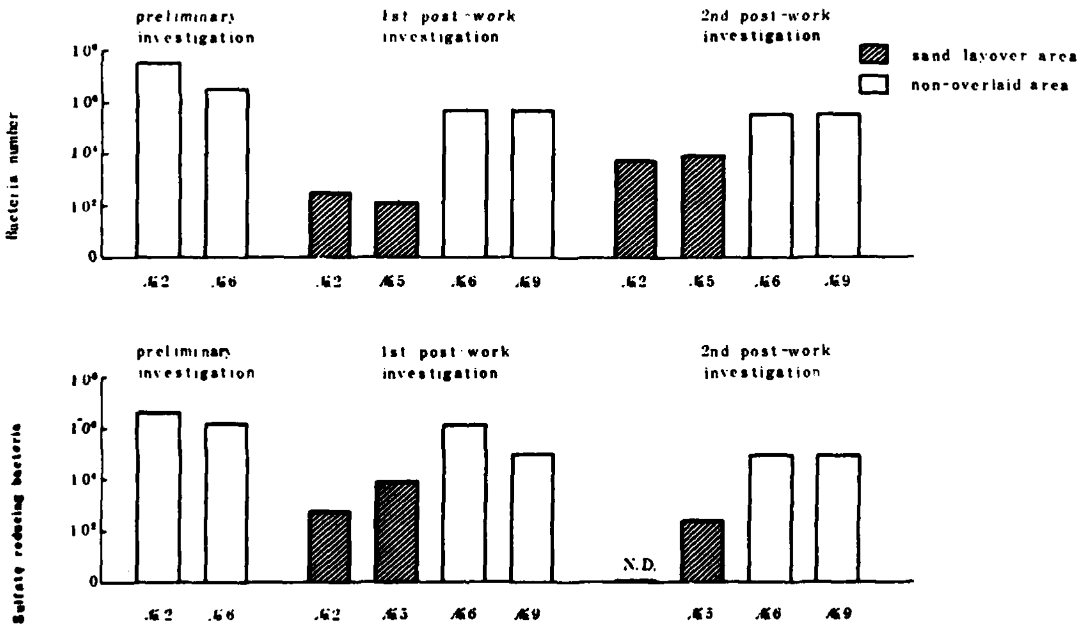


Fig. 23: Results of Bacteria Investigation

(d) In the preliminary investigation, Paraprionospio, a Polychaeta, often found in the soft mud rich in organic matter in the bay, prevailed in the benthos. In the post-work investigations, macrobenthos were found to decrease right after the sand layover, although the number of species and the population generally increased. This inclination is more noticeable in the sand layover area.

(e) The number of both bacteria and sulfate reducing bacteria decreased.

9. Conclusions

In order to assess the environmental improvements by the sediment improvement, follow-up investigations for dredging conducted in Osaka Bay and sand layover work in Hiroshima Bay have been performed. Six months after the works, the following effects were observed:

(1) Decline in COD, T-P, etc., on the rate of release from the sediments mud.

(2) Decline in oxygen consumption rate by the sediment mud.

(3) Improved interstitial water quality.

(4) Increase in population and number of species of benthic organisms in the sand layover.

(5) Decline in the number of bacteria and sulfate reducing bacteria on the sediment surface.

A long-term follow-up investigation will be necessary to see whether these effects are long lasting or not, since they were obtained from a short-term investigation. As for the water quality improvement by the decline of reduced load from the sediment, a water quality simulation has been conducted and studied under a separate task.

OCEAN DISPOSAL OF CONTAMINATED DREDGED MATERIAL: A CASE STUDY

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ABSTRACT

The regulation of the ocean disposal of dredged material is vested in the U. S. Army Corps of Engineers using criteria developed by the U. S. Environmental Protection Agency. The criteria require a comprehensive evaluation of the potential ecological effects such as toxicity and bioaccumulation of toxic substances. The domestic and international regulatory constraints are discussed and a case study of a harbor sediment contaminated with PCB's is presented.

BACKGROUND

Navigable waterways of the United States have played a vital role in the Nation's economic growth through the years. The Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material average about 290,000,000 cubic metres in maintenance dredging operations and about 78,000,000 cubic metres in new work dredging operations with the total annual cost exceeding $150,000,000 (1). Because many of the waterways are located in industrial and urban areas, sediments are often contaminated with wastes from these point and nonpoint sources.

Sediment contamination has generated concern that dredging and disposal may adversely affect water quality and aquatic organisms. Consequently, most of the concern has centered on aquatic disposal. In recent

years, the CE has disposed of approximately half of the material at open-water sites.

The lead responsibility for development of ecological criteria and guidelines regulating the transport and disposal of dredged and fill material was legislatively assigned to the Environmental Protection Agency (EPA) to share in consultation and conjunction with the CE. Moreover, the enactment of Public Laws 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972) and 92-500 (the Federal Water Pollution Control Act Amendments of 1972) requires the CE to actively participate in developing guidelines and criteria for regulating the discharge of dredged and fill material in ocean and inland waters, respectively. The focal point for the developmental research on these procedures was the CE Dredged Material Research Program (DMRP) (1,2).

LEGAL REQUIREMENTS

Marine Protection, Research, and Sanctuaries Act (MPRSA)

Section 103 of the MPRSA specifies that all proposed operations involving the transportation of dredged material for dumping into ocean waters must be evaluated to determine the potential environmental impact of such activities. This is accomplished by the Secretary of the Army and the Administration of the EPA acting cooperatively through the District Engineer and Regional Administrator. Environmental evaluation must be in accordance with criteria published by EPA in the Federal Register (3). Implementation of this evaluation program is aided by use of an EPA/CE Implementation Manual (4). The ocean dumping criteria also required that the published (3) interim ocean disposal sites be designated as final ocean disposal sites. Designation can only follow a comprehensive ecological investigation of each site and preparation of a site-designation Environmental Impact Statement by the EPA (3,5).

An ocean dumping evaluation must consider materials prohibited from disposal by international treaty (5) (Public Law 92-254); the environmental impact; the general compatibility of the material with the disposal site; the need for ocean dumping with a thorough review of alternatives; impacts on aesthetics, recreation, and economics; and impacts on other uses of the oceans. Evaluations in CE regulation 33 CFR Parts 320 through 329 and 209.145 must also be applied.

Legislative Considerations

Section 103 (6) of the MPRSA requires that the criteria developed for implementing the MPRSA shall consider but not be limited to the following:

"*(A) The need for the proposed dumping.*

(B) The effect of such dumping on human health and welfare, including economic, aesthetic, and recreational values.

(C) The effect of such dumping on fisheries resources, plankton, fish, shellfish, wildlife, shorelines, and beaches.

(D) The effect of such dumping on marine ecosystems, particularly with respect to--

(i) the transfer, concentration, and dispersion of such material and its by-products through biological, physical, and chemical processes,

(ii) potential changes in marine ecosystem diversity, productivity and stability, and

(iii) species and community population dynamics.

(E) The persistence and permanence of the effect of the dumping.

(F) The effect of dumping particular volumes and concentrations of such materials.

(G) Appropriate locations and methods of disposal or recycling, including land-based alternatives and the probable impact of requiring use of such alternate locations or methods upon considerations affecting the public interest.

(H) The effect on alternate uses of oceans, such as scientific study, fishing, and other living resource exploitation, and nonliving resources exploitation.

(I) In designating recommended sites, the Administrator shall utilize wherever feasible locations beyond the edge of the Continental shelf."

Final regulations and criteria controlling ocean disposal of dredged sediments were published by the EPA on 15 October 1973 (7) in the Federal Register. The procedures (criteria) for assessing the suitability of dredged sediments for ocean disposal consisted primarily of the elutriate test (5) in place of total sediment analysis. This procedure was used to address short-term water quality impacts but not the longer term benthic impacts. Bioassays were recommended only in general terms.

The MPRSA further required that the criteria for ocean disposal be updated at least every 3 years. The first updated criteria, which are

currently in effect, were published in the 11 January 1977 Federal Register (3). These criteria account for provisions of the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (Convention) and reflect legal challenges by the National Wildlife Federation as to the adequacy of the 1973 criteria (3,5). The Convention prohibits the ocean dumping of materials containing certain substances as other than trace contaminants. Compounds on the prohibited list are considered to be present in trace quantities when the dumping of dredged sediments containing these contaminants will not cause significant undesirable effects (3).

The potential for undesirable impacts of dredging and disposal and determinations of trace contaminants are assessed in the ocean-dumping criteria by means of bioassays of the liquid, suspended-particulate, and solid phases along with chemical analyses of the liquid phase. The impact of chemical constituents released into the solution can be addressed by comparing their elutriate concentrations with appropriate water quality criteria after taking initial mixing into account or through use of a liquid-phase bioassay.

The 11 January 1977 criteria (3) also require a thorough physical, chemical, and biological assessment of all ocean disposal sites prior to their designation as "final" and acceptable dump sites. At this time actively used ocean sites are listed as "interim sites."

EVALUATIVE REQUIREMENTS

Ecological Evaluation of the Transportation for the Dumping of Dredged Material into Ocean Waters

The potential effect of the ocean disposal of dredged material on marine organisms and human uses of the ocean may range from unmeasurable to important. These effects may differ at each disposal site and must be evaluated on a case-by-case basis. The Register (3) provides criteria for such an evaluation, with an emphasis placed on direct assessment of biological impacts, and the appropriate technical procedures are found in Parts 227 and 228 (3). These procedures and their relationship to each other are illustrated diagrammatically and completely described in the EPA/CE Manual (4).

Applicability

Section 103 of the MPRSA (6) requires that criteria for the issuance of ocean disposal permits be promulgated after consideration of the environmental effect of the proposed ocean dumping operation, the need for ocean dumping, alternatives to ocean dumping, and the effect of all proposed actions on aesthetic, recreational, and economic values, and on other uses of the ocean. The decision of a District Engineer to issue

or deny a permit and to impose specific conditions on any permit issued will be based on an evaluation of the permit application (Part 227) and upon the requirements for disposal site management criteria (Part 228) presented in Subchapter H of the Register (3).

Prohibited Materials

The first evaluation involves determining the presence of certain prohibited substances that may not be ocean dumped under any circumstances. If materials such as high radioactive wastes or chemical or biological warfare agents are present, the permit application must be denied without further consideration. Dredged material, however, is highly unlikely to contain these substances and must usually receive the full technical evaluation required by the criteria.

Exclusions from Testing

There are cases where dredged material is not considered chemically contaminated and would, therefore, cause negligible pollutional impact when discharged at an appropriate disposal site. Thus, material that meets the requirements of paragraph 227.13(b) of the Register (3) may be excluded from the technical evaluations required by Section 227.13(b) (3) and need be evaluated only in terms of its compatibility with the disposal site and the considerations of Subparts C, D, and E, and the appropriate sections of Part 228 (3). Dredged material that does not meet the exclusions must receive full testing for its potential for environmental impact. The evaluative procedures emphasize biological effects, rather than simple chemical presence of possible contaminants. Dredged material is separated for evaluation into three phases, as defined in paragraph 227.32(b)(1) (3). All three phases must be evaluated.

Liquid Phase

The liquid phase of dredged material may be analyzed chemically and the results evaluated by comparison to water quality criteria for all contaminants after allowance for initial mixing. The period of initial mixing, discussed in the EPA/CE Manual (4), must be considered in comparing the predicted concentrations to water quality criteria. If the water quality criteria approach is not taken, the liquid phase must be evaluated by bioassays. The direct bioassay approach is to be used when the liquid phase may contain major constituents not included in the water quality criteria or when there is reason to be concerned about possible synergistic effects of certain contaminants. In these cases liquid-phase bioassay can aid in evaluating the importance and the total net impact of dissolved chemical constituents released from the sediment during disposal operations.

Suspended-Particulate Phase

The suspended-particulate phase of dredged material must be evaluated for potential environmental impact by use of bioassays. The

bioassays are used to evaluate directly the potential for biological impacts due to both the physical presence of suspended particles and to any biologically active contaminants associated with the particulates and/or the dissolved fraction. Results of these bioassays must also be interpreted in light of initial mixing.

Solid Phase

It is generally felt that if a dredged material is going to have an environmental impact, the greatest potential for impact lies in the solid phase. This is because it is not mixed and dispersed as rapidly or to such an extent as the liquid and suspended-particulate phases and because bottom-dwelling animals live and feed in and on the deposited solid phase for extended periods. Therefore, unless there is reason to do otherwise, the major evaluative efforts should be placed on the solid phase. Bioassays are required for evaluation of the potential impact of the solid phase. Solid-phase bioassay must also be interpreted in light of initial mixing and must be conducted with appropriate sensitive marine organisms consisting of at least three species including one filter-feeding, one deposit-feeding, and one burrowing species.

Bioaccumulation

All biological evaluations of the suspended-particulate and solid phase are required to include an assessment of the potential for contaminants from dredged material to be bioaccumulated in the tissues of marine organisms. This is intended to assess the potential for the long-term accumulation of toxins in the food web to levels that might be harmful to the ultimate consumer, often man, without killing the intermediate organisms. Since concern about bioaccumulation is focused on the possibility of gradual uptake over long exposure times, primary attention is usually given to the solid phase that is deposited on the bottom. Bioaccumulation from the suspended-particulate phase is considered to be of secondary concern due to the short exposure time resulting from rapid dispersion of the suspended particulates by mixing. Because of the long-term nature of the concerns, bioaccumulation from the solid phase is best evaluated at present in the field. This can be done only when a historical precedent exists for the proposed operation; that is to say, past projects of similar pollutional characteristics were disposed at the site under assessment. Under these conditions a field assessment provides the most useful information because the animals have been exposed to the sediment under natural conditions for periods greater than are generally practical in the laboratory.

Initial Mixing

All data from chemical analysis of the liquid phase and the bioassays and bioaccumulation studies must be interpreted in light of initial mixing, as described in the EPA/CE Manual (4). This is necessary since biological effects, which are the basis for water quality criteria,

are a function of biologically available contaminant concentration and exposure time of the organism. Laboratory bioassays expose organisms to relatively constant concentrations for fixed periods of time, whereas in the field both concentration and exposure time to a particular concentration change continously. Since both factors will influence the degree of biological impact, it is necessary to incorporate the mixing expected at the site in the interpretation of biological data (4).

Initial mixing is defined in Section 227.29 of the Register (3) and detailed guidance on estimation of initial mixing may be found in Appendix H of the EPA/CE Manual (4).

Methods for incorporation of mixing estimations into the interpretation of water quality results and for liquid-phase and suspended-particulate phase bioassay data are included in the EPA/CE Manual (4).

Although the regulations (3) require the consideration of initial mixing and dispersion of the sediment after it reaches the bottom in interpreting solid-phase bioassay data, no objective method of doing so has been devised. Rather, there has been an attempt to incorporate the phenomenon of solid-phase sediment dispersion into the bioassay design to some extent. The concept expressed in the EIS on the ocean-dumping criteria (5) is that "EPA has chosen to allow some change in sediment characteristics or water chemistry as being reasonable, but no damage to the biota outside the region of initial mixing is allowed under these criteria." The solid-phase bioassay technique, therefore, does not evaluate the physical effects of massive sediment deposition immediately under the discharging vessel, since the primary concern is that damage not extend beyond the region of initial mixing. Instead, the technique generally approximates conditions near the disposal site boundary where sediment dispersion has reduced the depth of deposited sediment, rather than physical effects of the sediment.

Trace Contaminants

As described in the EPA/CE Manual (4), the presence or absence of trace contaminants (8) must be determined for all three phases of the material. Section 227.6 of the Register (3) is perhaps the key section of the criteria, since dredged material may not be ocean dumped if it contains any of the listed substances in greater than trace amounts. This is not defined in terms of numerical chemical limits whose environmental meaning is uncertain, but rather "...EPA came to the conclusion that the basis for regulation (of trace contaminants) should be the probable impact of these constituents on the biota and that the measurement technique used should be bioassays on the waste itself (5)." Section 227.6(b) (3) expresses in regulatory language the idea that trace concentrations should be defined as those too low to cause an environmental effect.

General Compatibility with the Disposal Site

Once the preceding criteria have been satisfied, the general compatibility of the dredged material with the proposed disposal site must be evaluated under Sections 227.9 and 227.10 (3). Both sections are rather subjective criteria, and no specific evaluative procedures exist for determining compliance with either section.

PERSPECTIVE

It should be made very clear at the outset that the policy of the United States acting through the MPRSA (Ocean Dumping Act) does not strictly prohibit the ocean dumping of dredged material. Rather, it regulates the dumping to prevent or strictly limit dumping which would adversely affect human health, welfare, or amenities of the marine environment, ecological systems, or economic potentialities (6).

The United States is also signatory to an international treaty or agreement that is implemented through the Convention of the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Dumping Convention (LDC)) (3,5). The signatory countries to the LDC are to take all practicable steps to prevent the pollution of the sea that is liable to create hazards to human health, to harm living resources and marine life, to damage amenities, or to interfere with other legitimate uses of the sea.

These critical domestic and international objectives are implemented through criteria promulgated by the Environmental Protection Agency which incorporates state-of-the-art biochemical evaluative guidance and testing procedures. The legislation (3,6,7) then requires that the dumping be permitted only after a determination has been made that the dumping will not unreasonably degrade or endanger human health, welfare, or amenities or the marine environment ecological system or economic potentialities.

Additional evaluative guidance is set forth in EPA's regulations to implement the Ocean Dumping Act under the international constraints. These are known as the Ocean Dumping Criteria and present the testing and evaluative procedures and specific constraints that must be applied to a proposed dumping operation. With regard to dredged material, it also presents important exclusions from the mandatory and comprehensive testing requirements. It should be noted that the LDC (8) has also promulgated broad exclusions from the mandatory testing and specific prohibitions for dredged material and sewage sludge proposed for ocean disposal. For those materials that cannot be excluded, a comprehensive laboratory and field evaluative scheme is applied to the specific project. The general constraints outlined in the criteria (3) are such that various tests are conducted, so that when the materials are dumped, reasonable

assurance is provided that no significant undesirable effects will occur due either to toxicity or bioaccumulation. As previously mentioned, there are numerous other constraints which must also be met, but these are the most rigorous.

Obviously, none of this language, which is taken directly from the legislation, the treaty, and the regulations, strictly prohibits ocean dumping with the exception of the trace contaminants provisions of the LDC, but does allow scientific interpretation as well as latitude and discretion in determining when effects are adverse and will result in unreasonable degradation or endangerment or result in undesirable effects (3,5,6).

CASE STUDY: NEW YORK BIGHT

The New York Bight in the Atlantic Ocean is a valuable natural resource which has been, and continues to be, subjected to multiple human uses and environmental stresses. The waters of the Bight are important for commercial and recreational fishing, swimming, recreational boating, and waterborne commerce as well as for the support of a diverse and productive natural community. Because New York City has historically been a population center, enrichment of the Bight with human wastes has occurred for more than two hundred years. In addition, industrial and technological development in the first six decades of this century without the proper concern for environmental protection resulted in the introduction of many chemical contaminants into the Bight.

A case study of the application of the testing requirements including the development of a bioaccumulation interpretative protocol to determine the effects of dredged material disposal in the Bight and to plan strategies for the management of the disposal operations is discussed in the following paragraphs.

Toxicity Testing

Section 103 of the MPRSA requires that an ecological evaluation be conducted for dredged material proposed for ocean dumping (3,4). The following describes the results of the ecological evaluation conducted prior to issuance of a permit for ocean dumping. Mechanical dredging was proposed by a private applicant with subsequent transport of the dredged material in bottom-dumping scows for disposal in the ocean. The ocean site was a designated dumping area. Bioassays were conducted on the liquid phase, suspended-particulate phase, and solid phase; the organism selection and results are presented in Table 1. Procedures for conducting the ecological assessment are those presented by EPA/CE Technical Committee (4).

The liquid and suspended-particulate phases were assayed using

Table 1. Bioassay results.*

	LC 50 or EC 50 (Critical)	% LPC	% Dilution After 4 hr	Within Acceptable Limits (LPC Greater than Dilution)?
LIQUID PHASE (96 hr):				
Skeletonema costatum	32.5%	0.325	0.318	Yes
Neomysis sp.	>100%	>1.0	0.318	Yes
Menidia menidia	ND	--	0.318	Yes
SUSPENDED-PARTICULATE PHASE (96 hr):				
Skeletonema costatum	5.05%	0.051	0.0069	Yes
Neomysis sp.	70.7%	0.707	0.0069	Yes
Menidia menidia	ND	--	0.0069	Yes

	% Survival in Control	% Survival in Test Sediment	% Difference (Control Test)	Is difference statistically significant (P = 0.05) and greater than 10%?	Within Acceptable Limits?
SOLID PHASE (10 days):					
Mysidopsis sp.	96	98	-2	No	--
Mercenaria mercenaria	10C	100	0	No	--
Nereis sp. or *Neanthes* sp.	98	96	2	No	--
Total Community	98	98	0	No	Yes

Note: LC 50 - Lethal concentration resulting in 50% mortality ("critical" refers to lower limit of 95% confidence level for minimum LC 50).
EC 50 - Effective concentration resulting in 50% inhibition (applies to phytoplankton).
LPC - Limiting permissible concentration (0.1 times critical EC 50 or LC 50).
ND - No significant difference in survival between 96-hr control and 96-hr 100% test concentration.

* After U. S. Army Corps of Engineers Public Notice No. 9393 (9).

Menidia menidia (fish), Neomysis sp. (crustacean), and Skelotonema costatum (algae). Interpretation was based on calculation of an LC 50 for the animals and an EC 50 for the phytoplankton (Table 1). Based on these concentrations, a limiting permissible concentration (LPC) was calculated by applying a safety factor of 100 (e.g., LC 50/100). The LPC must then be met at the perimeter of the mixing zone no more than 4 hours after dumping. The mixing zone in this case was an especially small volume of water bounded on the surface by the release zone (locus of points constantly 100 metres from the perimeter of the conveyance engaged in dumping at the moment of dump, ending at the last moment of dump) and extending to a depth of no more than 20 metres (3,4). Because of the almost instantaneous release feature of scow dumping, definition of the mixing zone offered an environmentally conservative level of protection from potentially harmful effects due to disposal. As shown in Table 1, dilution was calculated to be sufficient for both the liquid and suspended-particulate phases to meet the LPC and presumptively be rendered harmless.

The solid-phase bioassay utilized Mysidopsis sp. (crustacean) Mercenaria mercenaria (mollusc), and Nereis sp. or Neanthes sp. (polychaete) as test organisms with mortality and sublethal effects (if any) recorded. Results are shown in Table 1. In no case was mortality both statistically significant and exceed the LPC of 10 percent mortality. For greater statistical sensitivity, the data for each species were blocked and an analysis of variance determined for community effects. No effect was noted.

Chemical analyses were not conducted on the liquid phase; because of concern for synergism (3,4) or possibly antagonism, the liquid-phase bioassay was considered more protective than the water quality criterion for any single parameter. In addition, no behavioral or physiological abnormalities were noted in either of the three phases that could be attributable to sublethal effects.

The decision for issuance of the permit was then based on an evaluation of the probable impact of the proposed activity on the public interest (9,10). All other relevant factors that were considered included conservation, economics, aesthetics, general environmental concerns, historic values, fish and wildlife values, flood-damage prevention, land use, navigation, recreation, water supply, water quality, energy needs, safety, food production, and, in general, the needs and welfare of the people (9).

Bioaccumulation Interpretation (PCBs)

Section 103 (6) of the MPRSA requires an evaluation of the biological effects of the disposal while the Convention (3,5,8) constraints as implemented through domestic criteria specifically require an evaluation of bioaccumulation of materials prohibited (8) from ocean dumping as other than trace contaminants. The evaluation is made tc determine whether or

not there will be significant undesirable effects or hazards to human health. The following discussion is in regard to disposal of dredged material contaminated with a prohibited substance (3, 8) in an ocean environment that is somewhat stressed with these and other substances from a number of sources (e.g., dredged material, sewage sludge, and estuarine and river input).

Environmental Setting

Today the Bight exists as a stressed but viable ecosystem. Although in many respects the ecosystem appears to be holding its own, it cannot be expected to indefinitely withstand a continually increasing level of stress. Thus, the short-term goal is the management of dredged material discharges so that they will not cause a further reduction in the viability of the New York Bight. This action will prevent unreasonable degradation of existing environmental conditions. There is a further commitment to a realistic time frame for taking significant action to reduce any environmental stresses on the New York Bight which may be occurring today due to dredged material discharges.

Based on this approach, guidance was developed for interpreting laboratory bioaccumulation data in relation to the anticipated effects expected at the discharge site (Figure 1). This guidance will be revised as the data base becomes more complete. The interpretative guidance is not established as fixed and final numeric criteria but rather as an aid to interpreting test results. As such, it is open to review and updating as additional pertinent data become available.

This interpretative guidance approach will implement the legal prohibition against unreasonable degradation by preventing increased environmental stress in the Bight from dredged material disposal. It is believed that continued unrestrained discharge of dredged material that satisfies the Ocean Dumping Criteria, including evaluation of bioassay and bioaccumulation analyses using the interpretive guidance, will safeguard the ocean from further degradation. However, an accelerated program to increase the data base on tissue contaminant concentrations in the Bight environs is necessary so that a better understanding of the complex physical, chemical, and biological factors associated with ecological consequences of contaminants in dredged material discharged in the Bight is available. This and other information will be used to develop management plans to achieve the previously stated goal of optimizing the environmental acceptability of dredged material discharges.

Although major advances have been made in techniques for routinely utilizing bioanalytical procedures (e.g., bioassays and bioaccumulation) as a basis for making decisions on the acceptability of discharging dredged material in open-water habitats, the pace has not been kept in the ability to interpret the ecological significance of test results. These procedures have been applied for the last two years to evaluate applications for ocean disposal of dredged material at the New York

SPECIES EXHIBITING STATISTICALLY SIGNIFICANT BIOACCUMULATION

LEVEL OF ACCEPTABILITY	Nereis	Mercenaria	Palaemonetes	Nereis Mercenaria	Nereis Palaemonetes	Palaemonetes Mercenaria	Nereis Palaemonetes Mercenaria
				PCBs (PPM)			
Nereis	0.400			0.400	0.400		*
Mercenaria		0.100		0.100		0.100	*
Palaemonetes			0.100		0.100	0.100	*

* When all three test species bioaccumulate to a statistically significant level, the material is unacceptable for uncontained discharge at the EPA-designated Mud Dump Site.

Figure 1. Decision matrix (interpretative guidance) for evaluating statistically significant laboratory bioaccumulation results.

Bight ocean disposal site. The laboratory tests, though not directly indicative of field conditions, do serve to indicate the materials that may cause undesirable environmental impacts.

Bioassay results have demonstrated in some of the materials tested that bioaccumulation of PCBs by organisms from test sediments was occurring in levels that were statistically significant when compared to a control using a clean sand sediment and an artificial seawater medium. Because of the indication of potential for harm, it was necessary to evaluate available field PCB data to develop numerical guidance for the interpretation of laboratory-derived levels of PCB bioaccumulation in relation to effects upon dumping. This guidance was a decision-matrix (interpretative guidance) which specified a maximum PCB tissue level for each of the three test species which if met should prevent significant undesirable effects due to PCB bioaccumulation from occurring in areas contiguous with the dredged material disposal site.

Dump Site Area

The New York Bight Apex as defined for this evaluation is bounded on the north and west by Long Island and New Jersey, respectively, on the east by longitude 73°30'W and on the south by latitude 40°10'N. This area (approximately 625 square nautical miles) encompasses all of the principal ocean disposal sites for the New York metropolitan area (Figure 2). New York Harbor is normally divided into upper and lower bays. The seaward extent of the Harbor is defined by a transect drawn between Sandy Hook and Rockaway Point.

Methods

Research data were compiled on body burdens of PCB in marine vertebrates and invertebrates from the New York Bight Apex. The data are from a variety of both published and unpublished sources, and it is recognized that the data may not be completely comparable. Unfortunately, the paucity of data, the lack of a routine monitoring program, and the immediacy of need forced the assumptions for this interim effort that the data were derived in a consistent manner with similar concerns for quality control and that temporal differences were insignificant.

PCB values were converted as appropriate to mg/kg wet weight or mg/ℓ for consistency. For this study, all bioconcentration factors (BCFs) were calculated from the primary literature values for the water column and organism's body burden. Means and standard deviations were calculated for each set of data (either ambient water or by species) without the benefit of analyses of variance to determine if the data points were comparable.

The interpretative guidance (Figure 1) is considered a dynamic tool which will be frequently reviewed and modified as additional data and more detailed analyses become available. To this end the data presented in

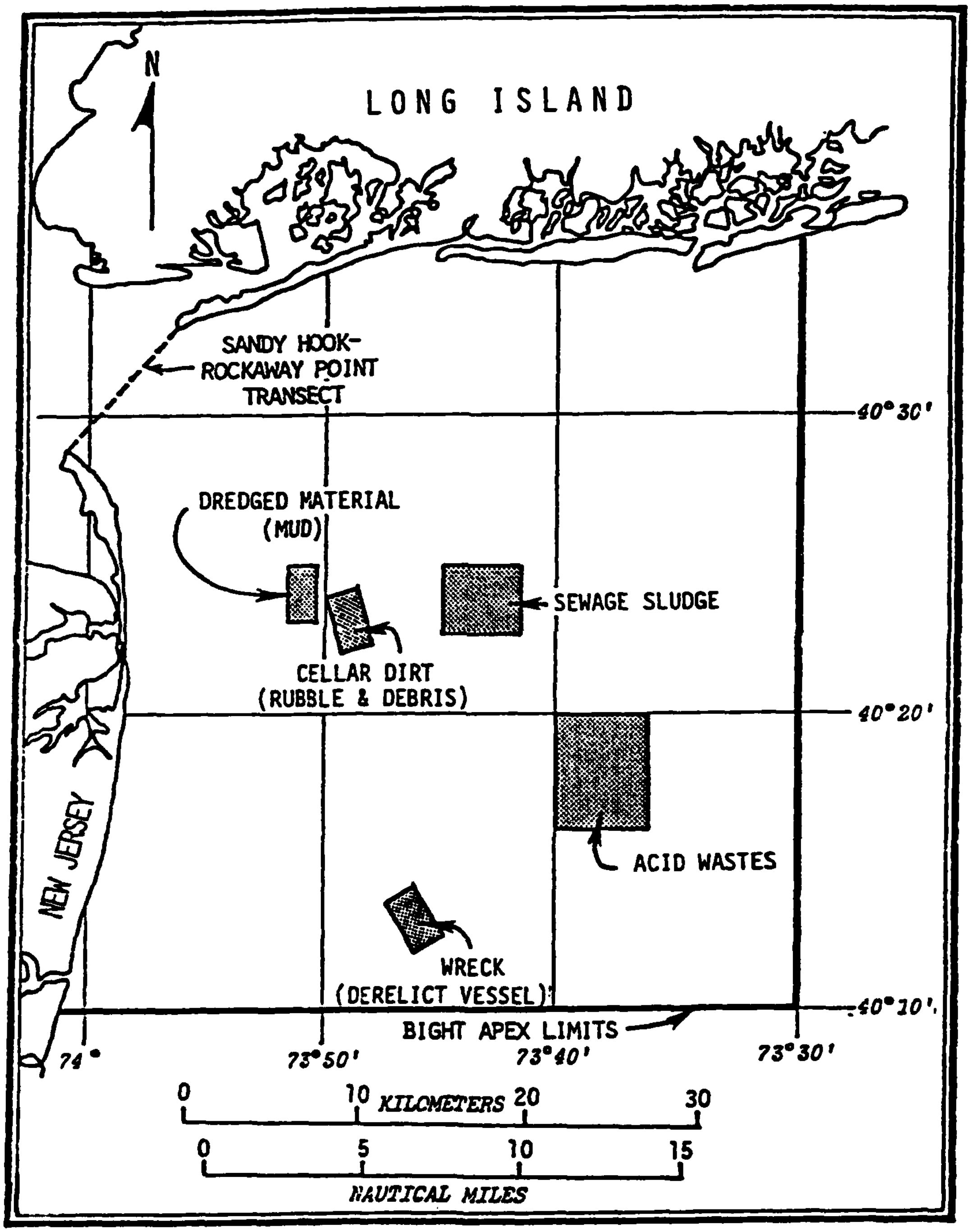

Figure 2. Major disposal areas in the New York Bight Apex.

this report will be subjected to rigorous multivariate regression analyses as soon as the guideline is implemented. Relationships between body burden and source of data, location, data of collection, species, water column, and sediment concentrations will be considered.

Results

Water column PCB values ranged between 1 and 200 ng/ℓ (parts per trillion) with the majority of values ranging between 10 and 44 ng/ℓ (11-17). The mean was 28.8 ng/ℓ (SD 47.1). The highest observed PCB value was recorded at the center of the Acid Waste Disposal Site, the lowest in the Cellar Dirt Disposal Site. Excluding the Acid Dump Site value, the mean water column PCB concentration was 17.3 ng/ℓ (SD 12.0).

In general, values appear to be highest along the eastern edge of the Apex followed by the south shore of Long Island, then by the near-shore New Jersey coast, and finally by the central Apex encompassing the Cellar Dirt and Dredged Material Disposal Sites. Elevated concentrations of PCBs along the south shore of Long Island may result from urban run-off from the bays, sewage outfalls, and some influence from the Hudson River plume. The Hudson River probably represents a more substantial input along the Jersey Coast. The highest value (in the center of the Acid Waste Disposal Site) may have resulted from a discharge which occurred shortly before the sample was collected, from a chemical release due to a pH change, or from a specific current pattern, or the number may simply be in error. The relatively high value (40 ng/ℓ) at a location approximately 7 miles NE of the Acid Waste Site suggests that the 200 ng/ℓ value may indeed be valid. Comparison of water column values with the detailed current data that have been accumulated in the past several years may give substantial insight into sources and routes of transport of this compartment of the PCB budget.

Although a considerable amount of PCB data has been collected in the Hudson River, there are few values reported for the Harbor. Thus far only 3 data points have been located: one from Gravesend Bay (8.0 ng/ℓ) and two from Raritan Bay (6.0 and 17.0 ng/ℓ). These fall within the range of values measured in the Bight.

Interpretative Guidance

In developing the interpretative guidance (Figure 1), the approach used was that the most conservative value recommended for PCB levels in fish (i.e., 0.1 mg/kg (18)) would be the interim limit established for accumulation in *Mercenaria* and *Palaemonetes*. The value for *Nereis* was established as a grand mean of existing values for invertebrates in the Bight (11,17). After compiling existing data (11,17), however, it was apparent that a grand mean approach was not viable for several reasons. Data were available on five species, but there was only one data point for one species (*Nereis*). Data for two other species (*Homarus americanus* and *Cancer irroratus*) had only been collected on edible muscle, not whole

body as in the other three species. Finally, one species, the surf clam (Spisula solidissima), did not appear to have the same propensity for accumulating PCB as that of the other four species; values for the surf clam were an order of magnitude lower than those of other species from the same location.

As an alternative to the grand mean concept, an interim limit for evaluating laboratory bioaccumulation of PCB in Nereis was based on levels of PCB in the water column and the potential for bioconcentration that can be expected in the Bight.

A cursory review of BCFs that have been published in the literature (Appendix 1) revealed that many organisms have the ability to concentrate PCBs three to five orders of magnitude greater than concentrations in the water. This appears to be related to the equilibrium partitioning between an organism's lipid pool and the surrounding water. The resulting body burden will depend, among other factors, on the size and quite possibly the chemical composition of the lipid pool. These two may be the controlling factors for interspecific differences of PCB evident in Table 1-1 of Appendix 1 and may explain the low levels in S. solidissima in the Bight.

Concern is justly raised on the mode of accumulation and transport of PCB in the marine community. Unfortunately, there are only limited studies that have been designed specifically to isolate uptake of PCB from the water, from food, and through trophic levels. Significantly, most studies (19-31) have reached the same conclusion that trophic-level amplification does not appear to be a major factor in the transfer of PCBs in marine organisms. Furthermore, in most cases (19-31), the dietary contribution to the body burden is less than the coefficient of variation associated with measuring uptake directly from the water.

For the purpose of computing the value to be used in evaluating laboratory data on Nereis body burden, several assumptions were made. First, a BCF of 10,000 is expected to occur in the Bight. This value is well below the maximum BCF for every species listed in Table 1-1 of Appendix 1. As is obvious from the following equation, the use of a low BCF in their context results in a low, and therefore environmentally protective, tissue concentration considered acceptable. Secondly, concentrations of PCB in the Bight can be expected to range between 10 and 44 ng/ℓ. Finally, the concentration of PCB which can be expected from direct uptake from the aqueous medium is defined by the equation:

(Water Concentration) (BCF) = Tissue Concentration

Of the marine invertebrates analyzed for PCB residues in the Bight, the largest data base (n = 21) was for the lobster Homarus americanus (11-17). The mean concentration of PCB in the edible flesh of lobsters from all locations was 0.144 (SD 0.075) mg/kg.

O'Brien and Gere (15) found no statistically significant difference between values from lobsters at the Dredged Material Disposal Site and those collected at a site along the New Jersey coast. Values from these two sites ranged between 0.062 and 0.320 mg/kg. The one value (37) from a site NW of the Dredged Material Disposal Site fell below this range.

While edible flesh values are important from a human health standpoint, for this discussion it is desirable to know whole body burdens. It appears that PCB is concentrated in the lobster's hepatopancreas and roe (both of which are consumed by humans) to many times the muscle values (33). Data collected by MESA (32) support the concentrating ability of the hepatopancreas. If the basic assumptions are accepted, then the whole body burden is approximately 0.246 and 0.502 mg/kg for males and females, respectively. On a soft tissue basis, the corresponding values are 0.471 and 0.961 mg/kg, respectively.

Data on the crab *Cancer irroratus* were also based on the analysis of edible flesh. Considerations similar to *H. americanus* probably also are applicable to the crab, and whole body concentrations should be substantially higher than those reported for muscle tissue. Unfortunately, data are not available for making similar extrapolations.

PCB concentrations in the muscle of *C. irroratus* (11-17) ranged between 0.003 and 1.813 ($\bar{x}$ = 0.314 ± 0.495, n = 16) mg/kg. The highest recorded value exceeded the next nearest by a factor of two and was collected immediately adjacent to the location of the lowest value (though at different times of the year). If this anomaly were deleted, the mean concentration would be 0.214 ± 0.302 (range 0.003 to 0.793) mg/kg. With the exception of the highest value, muscle tissue residues of PCB in the crab were generally an order of magnitude greater along the Jersey coast south to latitude 40°20'N than along the south shore of Long Island or in the vicinity of the disposal sites.

If the distribution of PCB in the tissue of *C. irroratus* is similar to those of the lobster, it may be expected that the whole body concentrations are two to four times those of the edible flesh.

Whole body concentrations (shell excluded) of PCB in the mussel *Mytilus edulis* ranged from 0.03 to 0.78 ($\bar{x}$ = 0.247 ± 0.217, n = 11) mg/kg. The highest values were reported from the Shark River Inlet with values nearer the New York Harbor entrance in the general range of 0.1 to 0.2 mg/kg (11-17).

The mean concentration (11-17) of PCB in whole body tissue samples (shell excluded) of the surf clam *Spisula solidissima* was 0.037 ± 0.18 (range 0.02 to 0.07, n = 17) mg/kg. As with the mussel, concentrations were highest off the Shark River Inlet. All values were an order of magnitude below those for other invertebrates from the same locations.

Only one value was found for the PCB concentration in polychaete

worms. MESA (19) analyzed a sample of mixed polychaetes from a location northeast (40°28'W, 73°48'N) of the Dredged Material Disposal Site. Their analysis indicated a whole body concentration of 0.18 mg/kg wet weight.

Data on a total of 20 individuals of 5 species of fish from four locations in the New York (11-17) were found in the literature. PCB concentrations for each species are presented in Table 2.

Although whole body concentrations of PCB in these species may be greater than the flesh values, the difference may not be as great as in the lobster. Analyses of the liver and roe of the mackerel indicated that PCB concentrations did not differ greatly from those of the flesh (19).

Table 2. Mean (±SD) and range of values for PCB residues in the flesh of five species of fish collected in the New York Bight (11-17).

Species	Sample Size	PCB Residues Mean (±SD) mg/kg	PCB Residues Range mg/kg
Scomber scombrus	5	0.204(0.086)	0.12 - 0.31
Scophthalmus aquosus	5	0.196(0.127)	0.06 - 0.32
Urophycis chuss	2	0.075(0.033)	0.052 - 0.098
Merluccius bilinearis	2	0.273(0.163)	0.158 - 0.386
Pseudopleuronectes americanus	6	0.127(0.056)	0.092 - 0.237

Discussion

The present review pointed out the deficiency of the existing data base: only a meager scattering of data points on a few marine species are available. Yet there are legal requirements that the test results and field conditions be interpreted in an effort to make rational decisions on the likelihood that dredged material will cause significant undesirable effects if discharged in the ocean.

The role that sediments play in the overall budget of PCB cycling in the marine environment remains unclear. Wildish et al. (34) have demonstrated that PCB adsorption to sediments is directly related to salinity. Stainken and Rollwagen (35) compared sediment concentrations of PCB to body burden in three species of bivalves in Raritan Bay. No statistically significant correlations could be found between: (1) sediment silt-clay content to sediment PCB content; (2) sediment silt-clay content to tissue PCB content; and (3) tissue PCB values to sediment PCB values. They did find that areas which were considered mixed sands and muds or medium sands contained relatively high values of PCB for sediments and tissues.

Reid (36) reported personal communications with Chytalo, who had studied PCB in sediment from three dredged material disposal sites and three nearby reference areas. The Eatons Neck dump site, in midwestern Long Island Sound, had a mean of 0.48 ppm dry weight Aroclor 1254 in sediments; its control area had 0.29. The Bridgeport disposal area, approximately 20 km east of Eatons Neck, had 0.27 ppm and its control area 0.15 ppm. The New London dump site and control area had 0.17 and 0.14 ppm, respectively. It was noted that for the Bridgeport and Eatons Neck reference areas, most PCBs were concentrated in the top 10-20 cm of the cores. Chytalo was also reported by Reid (36) to have examined PCB concentrations in the deposit-feeding polychaete Nephtys incisa from the disposal and reference areas named above. Only trace amount of PCBs (<1 ppb dry weight) were present in these polychaetes.

It was evident from the review of data on tissue residues that most of the species evaluated to date from a variety of locations in the Bight had similar PCB body burdens. The notable exceptions were the surf clam and ling (red hake). The range of values for many of the species exceeded the 0.4-mg/kg level suggested for the incorporation into the matrix, in some cases by almost a factor of two. Field data are lacking on polychaete worms to assess more accurately their susceptibility to concentrate PCB under field conditions. The one value reported here (0.18 mg/kg wet weight) is within the general range of concentrations measured in other organisms in the Bight and is well above the concentrations for Long Beach Sound polychaetes (36).

It is important to remember that the test organisms used in the interpretive guidance (Figure 1) were not selected especially for their own importance (either ecological or commercial) but as representatives of various trophic levels within the marine community. Thus, they serve as indicators of potential problems and identify materials which must be given careful consideration. The test has yet to be developed which can be accurately extrapolated directly from laboratory results to field conditions. For this reason interpretation of test results must go beyond routine statistics and encompass the ecology of the affected environment. The uncertainty of correspondence between laboratory results and actual field conditions is one of the principal reasons that preference is given in the Implementation Manual (4) to in situ assessment of bioaccumulation when a historical precedent exists for any particular discharge. As a consequence, it is necessary to establish a routine monitoring program which will enable future assessments in the field and not involve extrapolation from laboratory data.

It was recognized that Nereis represented a special group of marine invertebrates (infaunal) which were intimately associated with the sediments. The relative importance to these species of uptake of PCB from the overlying waters, from interstitial water, from the diet, and from incidental ingestion of sediments is not well known.

Elder et al. (37) used Nereis diversicolor to demonstrate uptake

from sediments spiked with an acetone solution of Phenochlor DP-5 (a French PCB). The concentration in the sediments was 0.23 mg/kg wet weight. After 40 days a tissue equilibrium was reached of approximately 0.71 mg/kg, representing a concentrating factor of approximately 3.5. They also observed a tissue concentration of 0.27 mg/kg in polychaetes exposed to control sediments which were not spiked with DP-5.

These authors (37) believed that they had demonstrated that N. diversicolor readily accumulates PCB from the sediments which they inhabit. Their study in fact did not demonstrate this. Acetone is among one of many surface-active agents which are used to maintain PCB in solution for bioassay purposes. Using this method to contaminate sediments probably binds the PCB loosely to the sediment and may enhance desorption into the water column. Thus, in the absence of both water column analyses and a study design which isolated water uptake from sediment uptake, the assumption that concentration was directly from the sediments cannot be supported.

Going beyond the question of the source of PCB from which Nereis may concentrate, it is important to consider the possibility of transport out of the disposal site. This is a major concern of the ocean dumping regulation, which accepts perturbation within the boundaries of the disposal site as long as significant undesirable effects do not occur in the adjacent environment.

Based on the limited amount of available literature (19-31), it is suggested that PCB transfer by means of trophic amplification through the food web is probably not of importance in the marine system. Furthermore, direct dietary uptake is probably insignificant in comparison to direct uptake from water. Thus, bioaccumulation by infaunal species of limited mobility would not appear to cause a serious threat of transport of PCB beyond the boundaries of the disposal site.

SUMMARY

Criteria have been published for the ecological evaluations of the transportation of dredged material for dumping into ocean waters. These guidelines and criteria were published in the Federal Register, Vol. 42, No. 7, Tuesday, 11 January 1977, for ocean dumping. A history of regulatory criteria development reveals that tests for describing the pollutional characteristics of dredged sediments were in use in the late 1960s and were similar to those used to evaluate the bulk characteristics of municipal and industrial wastes. This approach proved to be ineffective. Recent evaluative procedures use leaching tests for specific groups of contaminants, toxicity determinations, and bioaccumulation tests with various aquatic organisms, and general ecological evaluations of the proposed disposal sites. Subsequently, implementation manuals have been published and are in use. Relevant dredged material research

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was also discussed in light of input of the DMRP to these recently developed manuals for use as predictive procedures for pollution evaluation. Field evaluation and verification have shown these approaches to be effective environmental management tools.

A determination of bioaccumulation is a requirement of both the MPRSA (6) and the Convention (8) and can be evaluated either in the laboratory or in the field (4). In the case study of the New York Bight, a combined laboratory assessment and field interpretation was used for all dredging projects. For those projects exhibiting bioaccumulation, an interpretative guidance approach was developed where compliance with the legal prohibition against unreasonable degradation is ensured by accepting for ocean disposal only those projects that exhibit bioaccumulation below those levels found in the marine environment adjacent to the proposed dump site. The interpretive guidance reported here will be refined as more and better data become available and rates and levels of bioaccumulation are better understood. It is believed that the approach of laboratory evaluation interpreted in light of field conditions near the dump site environs allows scientific rationale and interpretation to be used to enable a determination of whether or not adverse and undesirable effects or unreasonable degradation will occur upon dumping.

APPENDIX 1: BIOACCUMULATION FACTORS (BCFs)

There have been many attempts to estimate BCFs for both freshwater and marine species. Techniques have varied from laboratory analyses (both long and short term) with individual Aroclors placed in solution with surface-active carriers to field studies of resident populations. As the methods have varied, so have the resulting values varied between researchers, species, and Aroclors.

Table 1-1 is a listing of some of the published BCF's for marine species. No attempt was made to do an exhaustive literature search. These values are intended to indicate the general magnitude of BCFs that can be expected in a variety of marine species.

Table 1-1. Bioconcentration factors (BCF) of Aroclor 1254 for a variety of marine species as determined through field and laboratory studies conducted by the referenced authors. BCF based on wet-weight values.

Species	Study Type	Length of Study days	Water Conc. µg/ℓ	BCF	Reference
Penaeus setiferus	Field	Resident	0.1	25,000	38
Callinectes sapidus	"	"	0.1	70,000	38
Cynoscion nebulosus	"	"	0.1	20,000	38
Invertebrate	"	"	$\bar{x}$ = 0.6	1,350[1]	39
"	"	"	0.03	230,000[2]	39
Fishes	"	"	$\bar{x}$ = 0.6	6,650[1]	39
"	"	"	0.03	70,000[2]	39
Palaemonetes pugio	Lab	35	0.04	5,250	40
" "	"	35	0.09	8,330	40
" "	"	35	0.62	26,580	40
Lagodon rhomboides	"	42	3.00	55,000[3]	41
Brachionus plicatilis	"	45	0.009	9,556[4]	42
Engraulis mordax	"	25	0.002	207,000[4]	42
" "	"	3	0.0025	195,200[4]	42
" "	"	2	0.0045	194,222[4]	42
Crossostrea virginica	"	168	5.00	85,000	43
" "	"	56	0.01	165,000	44
Leiostomus xanthurus	"	33	1.0	17,000	45
" "	"	56	1.0	27,000	45
" "	"	20	5.0	9,200	45
" "	"	26	5.0	24,000	45
" "	"	45	5.0	30,400	45
Lagodon rhomboides	Lab	14	5.0	2,800	45
" "	"	35	5.0	21,800	45
Cyprinedon variegatus (fry)	"	21	10.0	32,000	46
" " (adult)	"	21	10.0	32,000	46
" " (adult)	"	28	0.14	68,000	47

1 Average value.
2 Maximum value.
3 Value for Aroclor 1016.
4 Converted from dry weight values assuming 80% water content.

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PRODUCTIVE USES OF DREDGED MATERIAL

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ABSTRACT

In March 1978, the Environmental Laboratory at the U. S. Army Engineer Waterways Experiment Station completed the 5-year Dredged Material Research Program (DMRP). One of the major objectives of that program was to consider dredged material a manageable resource. To foster this new philosophy, productive use of dredged material and dredged material containment areas was included as an integral part of the DMRP. The approach was to identify and assess concepts and to develop specific information and guidance for implementation of the concepts.

This paper discusses the potential nonwildlife and wildlife uses of dredged material as researched in the Productive Uses Project (PUP) and Habitat Development Project (HDP) of the DMRP. The nonwildlife productive uses of dredged material were classified as industrial/commercial, recreational, agricultural, material transfer, waterway related, and multiple use. The wildlife use or habitat development use was classified as marsh habitat development, upland habitat development, and island or avian habitat development.

Findings indicate that, although generally haphazard or somewhat by chance, practically all categories of productive uses have been accomplished in the past. Because of little documentation on how and why, the research was directed at developing guidance that would allow future schemes to be planned and accomplished with a high probability of success.

INTRODUCTION

The increased dependence of the United States Army Corps of Engineers (CE) upon confined areas for disposal of maintenance dredged material has focused attention on alternative productive uses for the dredged material. The CE Dredged Material Research Program (DMRP) sought

to determine the environmental impacts of dredged material disposal and included the investigation of productive uses of dredged material and dredged material containment areas (4). The Productive Uses Project (PUP) and the Habitat Development Project (HDP) of the DMRP conducted studies directed at demonstrating that dredged material is a manageable resource. Research was aimed at productive uses of the dredged material from both a nonwildlife use standpoint (PUP) and a wildlife use standpoint (HDP). This paper summarizes the results of the five years of PUP and HDP research during the DMRP (1973-1978), in addition to much of the follow-up work carried on under the Dredging Operations Technical Support (DOTS) Program.

PRODUCTIVE USE CATEGORIES

Since the beginning of the DMRP, from 50 to 75 sites in 25 states and many foreign countries have been identified as productive use sites. Since the uses of the material or land at these sites were numerous, it was decided that it would be best to break the uses down into similar categories. Though there are numerous possible classification schemes, the scheme outlined below was considered appropriate for this article.

The two major divisions presented are nonwildlife uses and wildlife uses. In the nonwildlife area (PUP), the uses are classified as (1) industrial/commercial, (2) recreational, (3) agricultural, (4) material transfer, (5) waterway related, and (6) multiple use (9, 26). In the wildlife use area (HDP), the uses are categorized as (1) marsh habitat development, (2) upland habitat development, and (3) island or avian habitat development.

Nonwildlife Use

Nonwildlife productive uses are generally oriented toward uses of dredged material or dredged material containment areas by man to satisfy his needs. The following paragraphs discuss the six categories listed above and give a limited number of examples of each.

Industrial/Commercial

Probably the most common nonwildlife productive use of dredged material, at least in the past, has been the industrial/commercial use. This would essentially include port and residential development of disposal sites. Probably every major port in the world has some industrial/commerical facilities built on former dredged material disposal sites.

Port-related uses are so num ,us that no effort has been made to document all cases. The following are offered as examples and are typical of those found all over the world.

The Presidents Island-Memphis Harbor Project is located approximately 8 km southwest of Memphis, Tennessee. It is a 390-ha site filled with sandy dredged material. A slack-water area was created by diking, and an 245-m-wide by 3.6-m-deep channel was dredged and the sediments placed along 5.6 km of the channel's north bank. Filling was completed in 1957 and within 20 years most industrial development was completed.

Another United States river port where extensive use has been made of fastlands is Portland, Oregon, where the port has purchased thousands of hectares of land to receive dredged material. The 1095-ha Rivergate site is presently under development about 16 km from the city center. This area, largely underlain by compressible materials, receives silt from the Williamette River and sand from the Columbia River. A number of port and industrial facilities, including a steel mill, a grain terminal, and a container yard warehouse for barge receipt of paper products, have been placed on the site (9).

A major dredging project in Kingston, Jamaica, in the 1960's resulted in 107 ha of land being reclaimed for an industrial and commercial complex. The fill material came from excavation of the 10.7-m ship channel. A total of 3.5 million cu m went into the fill. Surcharges of up to 6.1 m were used to preconsolidate the soil, which allowed the warehouses and port transit sheds to be built on spread footings. At the time of development, plans called for residential uses on nearby reclaimed lands and a major program to modernize and beautify the area.

In southern Japan in the Kumanoto Prefecture, one of the world's largest shop building facilities was completed in October 1974. Hitachi Zosen's Anale Shipyard was built on land reclaimed by hydraulic fill from the coastal industrial area (12).

Industrial/commercial use generally fosters a high-intensity use of the area for buildings or major structures. This high-intensity use requires that engineering characteristics of the material meet strict standards. Coarse-grained material and finer grained material that has been allowed to consolidate and dry are the materials most suitable for such use.

Recreational

Recreational use is the second most common category of nonwildlife use. It is generally related to the industrial/commercial use, although it requires more open space, for instance, golf courses, tennis courts, baseball fields, etc.

An example of recreational use is East Potomac Park in southwest Washington, D.C., astride the confluence of the Anacosta and Potomac Rivers. Disposal operations were completed in 1925, whereby 133 ha was created from fine-grained clays and organic materials dredged from the

Potomac main channel. By 1925 the park reached full recreational development, and since 1939 ownership and operation of the facility have been in the hands of the United States National Park Service (NPS). The site currently offers four 9-hole golf courses, a snack bar, driving range, and clubhouse. Other recreational facilities include a swimming pool, indoor and outdoor tennis courts, eight baseball fields, as well as fields for field hockey, football, and polo. Buildings on the site include the NPS office, a maintenance building, comfort station, and several other minor structures.

The Patriots Point Project is a 182-ha recreational site immediately across the Cooper River, 1.6 km east of Charleston, South Carolina. This site, formerly known as Hog Island, was used for disposal of maintenance and new channel dredged material--primarily mixed sandy silt and clay--from 1956 to 1970; dikes were constructed of heavy clay. In the early 1970's, the Patriots Point Development Authority was established to plan and develop a recreational complex. The focal point of the present development is a Naval and Maritime Museum with the aircraft carrier YORKTOWN, moored at the site in early 1976, as the principal attraction. The Authority's Master Plan includes an 18-hole golf course, a 150-room motor inn with convention facilities, a 375-slip marina, and a 300-space recreational vehicle park. Long-range plans include construction of an oceanarium, aquatic theater, amphitheater, restaurant, and man-made lakes; it is also planned as permanent mooring of at least three more classes of decommissioned naval ships as the vessels become available. A dike-top tour route around the site will also be constructed. The project is forecasted ultimately to attract 1.5 million visitors annually. Structures at the site will be supported by pilings due to the compressible nature of the fine-grained dredged sediments and underlying organic material. An overburden of sand will be added to provide suitable drainage and foundation conditions for light structures and parking areas. Top soil, possibly including some dredged material, will also be placed in portions of the site to encourage vegetative growth, particularly in designated buffer zones (9).

Smith's Point Park in Suffolk County, New York, is located on Long Island between Narrow Bay and the Atlantic Ocean. The county owns and operates a hydraulic dredge for the purpose of dredging county-maintained channels and basins and simultaneously creating new marina and park facilities. Smith's Point Park, developed on a 207-ha site during an 612,000-cu-m maintenance dredging project, is 2.1 m above bay level and slopes up to a 6-m elevation on the ocean front. The park includes a clubhouse and a parking lot. This work has been labeled by the county as a "triple-benefit waterfront project" because it simultaneously maintained channels, created new park and marina facilities, and provided usable disposal areas rather than disposing of the material as waste (8).

The above examples are only a few of the many recreation facilities built on dredged material. Recreational use is one of the most popular uses, probably because it requires a relative minimum of planning and a relatively smaller cost to accomplish as compared to industrial/commercial uses. In addition, the nature of recreation sites with much open space and light construction is especially suited to the weak foundation conditions associated with fine-grained dredged material. Also, recreational land is generally for public use, and the high demand for public, water-oriented recreation encourages the development of recreational land-use projects.

Agricultural

In recent years there has been extensive interest in the potential of disposal of organic wastes on marginal agricultural land with the intent of increasing crop yields. Increased soil fertility is attained by improving the organic content, moisture-retention capacity, textural characteristics, clay-mineral distribution, aeration, pH, and other chemical and physical characteristics. Dredged material has been used as a soil amendment, and inactive dredged material containment areas are being used as agriculture land today. A greenhouse study on the agricultural value of dredged material was conducted in the DMRP, and the study results indicate that, under the right conditions, dredged material can be used to improve marginal agricultural land and can, by itself, support forage crop growth. However, the potential for success using dredged material is not only based on technical considerations such as the nature and extent of impermeable soils and their susceptibility to pollutant uptake, but also to a substantial degree on regional economic conditions and trends (10).

One DMRP study related to this point examined the feasibility of using dredged material containment areas to grow lawn sod or horticultural crops. There were no technical problems that could not be overcome; however, the market conditions governing the sale of lawn sod and horticultural crops limited the opportunity for the application of the concept. Specific market studies dealing with economic feasibility are necessary before instituting agricultural land-use concepts (2).

One site currently in agricultural production was identified in South Carolina. The Old Daniel Island disposal area in Berkeley County was used for maintenance dredging in Charlestown Harbor from 1953 until 1968. Dikes were constructed of heavy clay; material deposited was silts and fines. Of the 284-ha site, 180 to 200 ha have been truck-farmed for years. Almost all native crops have been grown successfully, with corn and soybeans showing the best yields. No special crop management techniques have proven necessary. Crops are marketed locally with no indication as to their source; no adverse public opinion has been heard. A second disposal site on the island, initiated in 1968, is nearly filled to capacity; upon complete filling it will be turned over to farming operations (9).

Although not strictly an agricultural use, the mariculture of shrimp in a conventional disposal site was field-tested with apparent potential for at least regional application. In an 8-ha portion of an active 64-ha containment area, approximately 700,000 juvenile brown shrimp, sustained exclusively on the nutrient value of dredged sediments from the Gulf Intracoastal Waterway in West Galveston Bay, Texas, were grown to a marketable size in about 3 months. Excellent growth and survival rates were noted, and chemical evaluation resulted in issuance of a U. S. National Marine Fisheries certificate of wholesomeness for human consumption. The shrimp were successfully test-marketed through wholesale and retail food and bait outlets (20).

For successful agricultural or mariculture use, fine-grained sediments hold the most potential since the physical and chemical characteristics of these materials are such that they support such endeavors.

Material Transfer

In recent years great attention has been given to the reuse or recycling of materials. The same attention has been given to the reuse of dredged material, particularly as it relates to the opportunities for reusing containment areas after previously deposited material has been removed. During the course of the DMRP study, a number of sites were identified where the dredged material had been transferred from the disposal site for a productive use elsewhere. For instance, a feasibility study indicated that dredged material could be used in solid waste disposal. The coarse-grained material could be used in leachate drains and gas vents, and the fine-grained materials could be used as cover and liner material (3). In Bay City, Michican; Wilmington, Delaware; and Alameda, California, dredged material was removed from disposal sites to be used in a landfill operation (9).

Dredged material has also been sold as fill material for such items as highway construction. The U. S. Army Engineer District, Philadelphia, has sold about 2.1 million cu m between 1972 and 1976. The Savannah District has given away probably 750,000 cu m. The Galveston District has sold about 375,000 cu m from various disposal sites. The Sacramento District has sold about 15 million cu m to the California Division of Highways for interstate highway construction (9).

Within the DMRP, a small field demonstration reclaiming about 0.8 ha of barren, strip-mine land with dredged material from a disposal site in Chicago, Illinois, was conducted. The material was trucked from Chicago, about 110 km to Ottawa, Illinois, where it was placed in a 0.9-m lift on a leveled strip-mine area. Five species of grasses were planted, and leachates and runoff water were monitored (19, 24). So far, reclamation has succeeded; vegetation has flourished and very little, if any, runoff or leachate contamination has resulted from the dredged material (11).

The Rock Island District is presently conducting a feasibility study examining the possibility of using dredged material to reclaim abandoned strip-mine land along the Illinois Waterway. The study will include analysis of institutional as well as technical factors bearing upon successful implementation. The study will: inventory abandoned strip-mine land suitable for reclamation along the water, inventory dredged material supplies in the waterway, make recommendations for the most suitable sites, and draw up plans for some of the most appropriate sites.

Waterway Related

Dredged material is often used for purposes closely related to the maintenance, preservation, and expanded use of waterways and the surrounding lands. These functions are classified under the heading of waterway related use (7). They might include such items as shore protection, beach nourishment, breakwaters, river control, etc. Successful implementation of such uses of dredged material is greatly influenced by the method and sequence of the dredging operation as well as the layout of the disposal area. Waterway related use normally involves the creation of landforms and thus permits opportunities for immaginative multiple use site development. These landforms commonly result in a secondary recreational use.

In Duval County, Florida, sand dredged during maintenance of the St. Johns River entrance to the Port of Jacksonville, Florida, has been used for the restoration of an eroding beach. The beach serves as protection to upland properties and is also used for recreational purposes. Beach use requires a particular set of circumstances that are related to the distance between the dredging site and the eroding beach and is dependent on the quality of the dredged material. The material to be dredged has to be clean sand and should reasonably match existing beach material in grain size and color. The dredging work serves the multiple public purposes of maintaining navigaion, protecting uplands, and restoring beaches. There are numerous cases of the use of dredged material for beach restoration in Florida and in California (9).

Along the Columbia River in Oregon and Washington, sand dredged from a navigation project has been used extensively for river control projects. The primary use is to place the material along existing banks to confine the flow of the river and thus assist in channel maintenance. The material thus placed also creates an excellent recreation area for use by swimmers, fishermen, and picnickers (15).

For a channel dredging project in San Diego, California, instead of making a conventional rectangular fill area along the existing shoreline, the sand, shell, and silt fill has been used to form the protective outer breakwater for a marina. The breakwater is sufficiently wide to be used as a park, fronting on both the marina and the bay. The

landform itself does significantly contribute to the quality of the use of the land.

A similar example can be found along the Columbia River navigational channel at Kalama, Washington, where sandy dredged material has historically been pumped along the shoreline to constrict the river, protect the banks, and provide informal recreation areas. Hydraulic model studies of the Kalama area have indicated that channel maintenance dredging could be reduced by a substantial reduction in the width of the river. Under conventional practices, this would have been accomplished by permeable groins being placed at right angles to the river and dredged material being pumped between the groins. It was recognized that the same objective could be accomplished by placing the sand in the shape of a "L" with the short leg at right angles to the shoreline and the long leg heading downstream, parallel to the existing beach. The land thus created would have water on all sides, but, more importantly, the 4-ha water area between the "L" and the existing beach would provide a harbor for launching and mooring small craft. This water area would be protected from river currents, wind, waves, and wakes from passing deeper draft vessels. A park has been constructed at the upstream end of the fill and a launching ramp at the outer end of the "L." Initial construction of a marina was completed in 1977 (9).

A sand breakwater has been constructed at Saldanha Bay, South Africa, using dredged material. The breakwater is part of the Sishen-Saldanha Bay project, which includes a railway line from the Sishen iron ore mines and an ore export port at Saldanha Bay. The sand breakwater was selected over a conventional rock or concrete structure after extensive testing of wind and wave characteristics in the bay. The breakwater will provide protection for the proposed port facilities as it connects the mainland with an existing offshore island (23).

Nearly all of the waterway related uses incorporate dredged material of a sufficiently high quality that enable it to be pumped in place and to provide some structural characteristics to withstand the eroding forces of waves, winds, and currents. In most cases planners are able to take advantage of the characteristics of the dredged material and the geography of the area to provide a highly productive land resource.

Multiple Use

The conventional approach to site development and subsequent use of the disposal areas is to consider the material dredged as a constraint on future development or use of the site. For instance, disposal areas filled with silt and clay can be expected to offer poorer foundations and have settlement problems. Several projects were identified where careful planning and material placement enabled the developer to largely overcome the inherent problems of the dredged sediments or the site.

Along the shoreline in Toronto, Canada, numerous commercial, transportation, and recreational sites have been created by the combined use of landfill and dredged material. Aquatic Park, under development by the Toronto Harbour Commissioners, is an excellent example of where the form of the land created can enhance the number and quality of productive uses. Construction rubble was used to create an approximately 4.8-km-long headland running at an oblique angle to the natural shoreline. The headland is essentially linear, but has numerous indentations in its shoreline dike. Dredged material was placed in the water behind the rubble dike where protection was afforded from wave and tidal action and associated erosion. The dredged material was placed to form contours for the development of lagoons and lakes along and behind the shoreline. The resultant configuration of the headland resembles natural landforms in the area. The length of shoreline is many times the length that would have resulted from a conventionally shaped disposal area and thus opportunities for shoreline utilization were increased (9).

During the 1920's, a massive dredging project was carried out to realign the Willamette River in Portland Harbor, Oregon. Several major landfills were created from the silt and sandy dredged material. On the west bank of the river, a massive landfill resulted in a large area of primarily industrial land known today as Guilds Lake Industrial Area. This area has evolved into a multiple-use transportation and modern industrial center. On the east bank, an existing island, Swan Island, was raised above flood level and connected to east Portland by means of a causeway constructed with dredged material. Swan Island had no planned function beyond being a dredged material disposal site, but in the 1930's the island was converted into Portland's first airport. The airport was subsequently moved to another site in 1939 and most of Swan Island was devoted to a shipyard for the construction of tankers and freighters. Prior to 1945, the shipbuilding facilities were converted to a ship repair yard, a use which continues today. The remainder of the island is still under development as a planned industrial park.

Also located on Swan Island is "Port Center," a commercial site developed as a result of the planned sequential placement of dredged material. At the time the island was raised above flood level using dredged material, a notch was left at the upper end of the island to provide an access channel to a grain export facility then in operation. In the 1960's the grain facility became obsolete and was demolished. It was then decided to fill the notch to serve three purposes:

(1) Provide a site for dredged material disposal.

(2) Channelize the current to reduce shoaling in the navigation channel.

(3) Provide a site for commercial development.

The dredged material consisted mostly of silt and clay and some sand. The sand was deposited along the outer edge of the notch-fill area to provide an enclosed dike. The softer silt and clay were pumped into the enclosed area and the solids were allowed to settle out. Some of the sandy dredging locations were not worked until the end of the fill operation so that the top 1.5 m of fill would be composed of the coarser, more stable material for placement of the commercial structures. The softer, less stable material was placed to coincide with parking and landscaped areas. The resulting land uses, e.g., restaurants, various commercial enterprises, and a low-rise office building, were possible because of the sequencing of the fill. A substantial amount of planning and site exploration was required to carefully manage the dredging and filling operation and to identify the location of the granular material (9).

The North Channel in Grays Harbor at Hoquaim, Washington, provides access between the Pacific Ocean and the export docks at the Port of Grays Harbor. From maintenance dredging of the channel beginning in the early 1930's, a dredged material fill area has accumulated that is approximately 3.2 km long and 150 m in width. The material is a mixture of sand and silt. Presently, there are a variety of uses on the site including a municipally owned airport, a sewage lagoon, and a privately owned sawmill. This site was particularly suitable for the airport and sewage lagoon due to the scarcity of flat land in the area. Although these land uses are well established today, they were not a part of the original project planning.

Multiple land use experience has taken place at Galveston Bay, Texas, where large areas were set aside for receiving dredged material in the late 1800's and are still in use for that purpose. These disposal areas were created for maintenance dredging of silt, clay, and sand, and no other use was planned when dredging and filling operations were initiated. Today, one such area known as Pelican Island, located on the Galveston Ship Channel northeast of the City of Galveston, contains recreation areas, port terminals, manufacturing uses, commercial offices, a shipyard, and a college.

The use of a site at Beaufort Island, Morehead City, North Carolina, for disposal of dredged material was initiated in 1935 and completed in 1950. The dredged material was silt and sand, and the dredging was performed for channel deepening and maintenance. At the present time, the property is in the hands of 22 owners, including the State of North Carolina. Uses on the site include a State recreation park, warehousing, port-related terminals and storage areas, single family housing, retail and office space, and military facilities including a Navy LST ramp and a Marine embarkation area (9).

Wildlife Uses

Wildlife or habitat development uses refer to the establishment of relatively permanent and biologically productive plant and animal habitat. The use of dredged material as a substrate for habitat development offers a disposal technique that is, in many situations, a feasible alternative to more conventional disposal options (21).

As stated, three general habitats have proven to be suitable for establishment on dredged material: marsh, upland, and island. The following paragraphs discuss and give examples of these habitats as productive uses.

Marsh Habitat Development

Any community of grasses or herbs that experiences periodic or permanent inundation is considered a marsh. Typically, these are intertidal freshwater or saltwater marshes and relatively permanently inundated freshwater marshes. Marsh habitat development with dredged material is considered a viable productive use because marshes are often recognized as extremely valuable natural systems and are accorded importance in food and detrital production, fish and wildlife cover, nutrient cycling, erosion control, floodwater retention, groundwater recharge, and aesthetics (21).

Marsh development is the best understood of the habitat development alternatives, and accurate techniques have been developed to estimate costs and to design, construct, and maintain these systems (13). During the DMRP, marshes were developed at six sites throughout the United States. Table 1 lists those sites and shows the parameter ranges for the studies. As can be seen, salinity ranged from brackish to fresh, grain size ranged from fine to coarse, and the setting ranged from purely riverine to estuarine (13).

Until the end of the DMRP, marsh habitat development was never a planned disposal activity. Marshes were developed, but merely by chance and very little documentation existed. Since the DMRP, marsh development has, in a few cases, become a planned disposal alternative. The following paragraphs discuss a few post-DMRP dredged material disposal sites where marsh development is being planned or actually carried out. In addition, these sites are not research sites, but are actual disposal sites.

The Detroit District, in connection with other Federal and State agencies, is actively involved in planning and constructing a dredged material disposal area for restoring a marsh at Pointe Mouillee game area on Lake Erie in the State of Michigan. The area will contain approximately 1010 ha of marsh and will be actively managed for maximum wildlife use (25).

TABLE 1. SUMMARY OF HABITAT DEVELOPMENT FIELD SITES*

Site	Location	Type of Habitat	Substrate	Salinity	Exposure to Wind/Wave Energy	Size (ha)	Summary Report Citation
Miller Sands	Lower Columbia River, Astoria, OR	Marsh and Upland	Sand	Fresh	Medium	94.7	Clairain et al. (5)
Salt Pond 3	South San Francisco Bay, CA	Marsh	Clay	Saline	Low	40.4	Morris et al. (18)
Bolivar Peninsula	Galveston Bay, TX	Marsh and Upland	Sand	Saline	High	7.3	Allen et al. (1)
Drake Wilson Island	Apalachicola Bay, FL	Marsh	Silt Fill Sand Dike	Saline to Brackish	Low	19.2	Kruczynski et al. (16)
Buttermilk Sound	Atlantic Intracoastal Waterway, Brunswick, GA	Marsh	Sand	Fresh to Brackish	Medium	2	Cole (6)
Windmill Point	James River, Hopewell, VA	Marsh	Silt Fill Sand Dike	Fresh	Medium	8	Lunz et al. (17)
Nott Island	Connecticut River, Essex, CT	Upland	Sand and Silty Sand	Fresh with Salt Wedge	NA†	3.2	Hunt et al. (14)

* Based on Hunt (1978).
† Not applicable.

A second, full-scale marsh development site is located in the southern end of San Diego Bay. The Port of San Diego initiated construction in 1979 and plans to complete planting in the spring of this year. Both the containing dikes and the marsh surface are fine-grained dredged material removed from a small boat basin nearby. The diking material (278,000 cu m) was dredged in 1978 and allowed to dewater before placement by truck at the site, whereas the marsh surface within the dikes is a result of placement of the remainder of the dredged material (300,000 cu m) by hydraulic dredge. The area of the site is approximately 27 ha.

In addition to the above actual marsh development sites, the DOTS Program has conducted feasibility studies considering marsh development for a number of CE District Offices throughout the United States.

Upland Habitat Development

Upland habitats encompass a variety of terrestrial communities ranging from bare soil to dense forest. In the broadest interpretation, upland habitat occurs on all but the most disturbed disposal sites. For example, a gravelly and bare disposal site may provide nest sites for killdeer; weedy growth may provide cover for raccoons or a food source for seed-eating birds; and water collection in desiccation cracks may provide breeding habitat for mosquitoes. The essential fact is that man-made habitats will develop regardless of their management; however, the application of sound management techniques will greatly improve the quality of those habitats. Upland habitat development has potential at hundreds of disposal sites, and its implementation is largely a matter of the application of well-established agricultural and wildlife management techniques (21).

In the DMRP upland or terrestrial habitats were developed at three sites (Table 1). As in the case of marsh development, upland habitat on dredged material has occurred in the past although not under planned circumstances. The DMRP offered the opportunity to plan such development and, as a result, more and more nonresearch, full-scale upland habitat development on dredged material is now being planned and accomplished. For instance, along with the 1010 ha of marshes at Point Mouillee in Michigan will be an additional 365 ha of upland habitat.

As in the case of marsh development, the DOTS Program has developed or evaluated 20 or so major upland habitat development plans involving the use of dredged material. In addition, any number of minor inquiries have also been answered.

Island or Avian Habitat Development

The last, but not least, productive wildlife use is island habitat development. Island habitats are herein considered terrestrial

communities, completely surrounded by water or wetlands, and distinguished by their isolation and limited food and cover (21). Because they are isolated and relatively predator-free, they have particular value as nesting and roosting sites for numerous species of sea and wading birds (gulls, terns, egrets, herons, and pelicans).

Dredged material islands are found in low to medium energy sites throughout the United States and range in size from a few square metres to several hundred hectares. Typically, these islands are located next to navigation channels and are characteristic of the Intracoastal Waterway. They are generally composed of sandy and shelly dredged material, although some fine-grained material islands do exist.

As stated, their primary habitat value is nesting and roosting sites for birds. Regional studies by the DMRP located approximately 600,000 colonial nesting waterbirds on those dredged material islands surveyed. Many more have been noted on islands outside the study. In addition, it is anticipated that the islands will become even more valuable as the human population continues to increase and demands are placed on the mainland coastlands and swamplands.

Management techniques have been developed within the DMRP for managing dredged material islands for colonial waterbirds. These techniques not only allow bird use but also foster its use, and not only allow for periodic dredged material disposal but also require periodic disposal to maintain target habitat diversity.

The feasibility of these management recommendations has already been demonstrated by the Wilmington District. They have been practicing such management on a local, annual basis for several years and have developed a proposed long-range colonial waterbird management plan for the lower Cape Fear River Estuary (22).

SUMMARY AND CONCLUSIONS

The disposal of dredged material is a major problem confronting coastal and waterway areas in the United States. However, numerous examples of the productive uses of dredged material show that it can indeed be a valuable resource.

The PUP and the HDP of the DMRP have established the technical feasibility of productive uses of dredged material. Dredged material containment areas can support almost any land use if the planning, engineering, and project execution are performed with the end use in mind. However, achievement of productive land uses with dredged material is a complex problem often requiring skills and costs not required by former disposal techniques.

This paper documents examples of productive land uses of dredged material. The examples were obtained from published literature and project descriptions and discussions with persons knowledgeable in the planning and execution of dredging projects.

Feasible nonwildlife uses were documented within the following land-use categories: industrial/commercial, recreational, agricultural, material transfer, waterway related, and multiple use.

Wildlife uses offer an alternative dredged material disposal method that is often feasible from biological, engineering, and economic standpoints. Three general habitats have proven feasible for establishment on dredged material: marsh, upland, and island or avian. Careful use of this alternative could significantly increase the extent of wetland and wildlife resources in many parts of the United States.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

U.S./Japan Experts Meeting on the Management of Bottom Sediments Containing Toxic Substances, (6th : 1981 : Tokyo, Japan)

Management of bottom sediments containing toxic substances : Proceedings of the 6th U.S./Japan Experts Meeting, 16-18 February 1981, Tokyo, Japan. -- [Vicksburg, Miss. : U.S. Army Engineer Waterways Experiment Station] ; Springfield, Va. : available from NTIS, 1982.

406 p. ; ill. ; 27 cm.

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Dredging Operations Technical Support Program.

Controlling office: Water Resources Support Center.

Monitored by Environmental Laboratory. U.S. Army Engineer Waterways Experiment Station.

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